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IEP NEWSLETTER

Interagency Ecological Program for the San Francisco Estuary

OF INTEREST TO MANAGERS

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The North Bay Aqueduct sampling program caught 44,557 fish—574 were delta smelt. This almost doubled the number caught (309) in 2000. On nine separate dates between April 7 and May 25, delta smelt catches in Barker Slough triggered pumping restrictions for the North Bay Aqueduct Pumping Facility.

Catch of fall-run chinook salmon smolts by the USFWS at Sacramento was the highest for the July through September period since 1995.

Adult sturgeon tagging started in August, a month earlier than usual in an attempt to collect green sturgeon for UCD researchers. Twenty-three legal size (117 to 183 cm total length) green sturgeon and 208 legal sized white sturgeon were caught in August. Of these, 22 green sturgeon and 197 white sturgeon were tagged. In the first nine days of sampling in September, 15 green sturgeon and 140 white sturgeon were tagged. Sublegal size sturgeon were also abundant with 99 green sturgeon and 70 white sturgeon caught in August.

The CALFED Science Program Expert Review Panel on hydrodynamics and salinity response to levee breaches in the Suisun Marsh reviewed modeling results and data from a variety of sources and offered three conclusions: (1) modeling and field evidence show that levee breaches in the Suisun Bay and Marsh do affect Delta salinities; (2) possible physical mechanisms include tidal asymmetry, tidal range reduction, baroclinicity effects and tidal energy changes; and (3) additional work is needed to identify key mechanisms for this salinity mixing.

Recent work by Dr. Carol Lee of the University of Wisconsin suggests the copepod *Eurytemora affinis* found in the San Francisco Estuary is most likely from the East Coast of the United States and was probably introduced when striped bass were transplanted in the late 19th century. This copepod was assumed to be a native species before this work was published. *Eurytemora affinis* was considered a major food item for striped bass and delta smelt before it was mostly replaced by other exotic copepods.

The IEP Resident Fishes Project Work Team held a one day thematic meeting on green sturgeon. Researches from the Central Valley watershed and San Francisco Estuary, Klamath River and Columbia River met to discuss their respective research and findings. This article provides short synopses of the work being done by a number of researchers and presents some of their findings.

The Dayflow program has been updated to correct some minor problems and is currently available on the IEP web site http://www.iep.water.ca.gov/dayflow/. People are encouraged to review the changes and to download the latest version of this valuable data.

The Pacific herring is a valuable commercial species that plays an important ecological role in estuaries on both sides of the Pacific Ocean. Comparisons of embryo and larval development in relation to temperature and salinity for herring from San Francisco Bay and Akkeshi-ko in Hokkaido, Japan, show a similar salinity range and optimal salinity.

Water quality sampling of Central, San Pablo and Suisun bays during 2000 and 2001 showed spring and fall peaks in alga biomass. The spring peak was composed mostly of large phytoplankton cells while the fall peak was mostly smaller cells. During both events ammonium was the chief source of nitrogen for algae. Silicate and nitrates were not limiting factors.

A preliminary study of the stable isotopes in the Yolo Bypass and Sacramento River food webs was unable to find evidence of major differences between the food webs of these two areas. There was some evidence that a difference was developing the longer fish stayed in either area. Large isotope variability among primary produces was the main reason no difference was found.

Analysis of the 1984-1993 striped bass larval fish data found the growth rates of larval striped bass range between 0.13 to 0.27 mm per day. Differences in growth rates between years was mostly explained by prey densities. Temperature was not found to influence growth rates. No evidence of density dependent mortality in larval striped bass was found.

Quarterly Highlights

Suisun Marsh Salinity Control Gates

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Ultrasonic tagging of adult fall-run chinook salmon began on September 24 at the Suisun Marsh Salinity Control Gates in Montezuma Slough. The study focuses on adult salmon use of the boat lock for upstream passage when the salinity control gates are tidally operated and the flashboards are installed.

Tagged salmon are externally marked with Floy T-bar tags, which are imprinted with the DFG Bay-Delta office's return address. This external tag will visually identify ultrasonic-tagged fish that may be recaptured during tagging and provide further migration information through sport fishing catch, creel census surveys, and at the hatchery.

Fixed hydrophone stations are located upstream and downstream of the gates, and at both ends and the center of the boat lock. Each station has receivers and palmtop computers to monitor and record the passage of tagged salmon during each operational phase of the study.

A total of 198 adult salmon (66 per phase) was implanted with ultrasonic transmitters upstream of the salinity control gates every other week from September 24 through October 26. Monitoring continued through November 2.

A concurrent study will track the migration of ultrasonic-tagged adult chinook salmon through the Sacramento and San Joaquin rivers using a series of fixed hydrophone stations.

San Francisco Bay Fisheries Monitoring

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The San Francisco Bay Study continued to sample fishes and macroinvertebrates in the bay monthly from July to September 2001. Some of the general trends reported in the last newsletter continued, with relatively high catches of some cold-temperate water species, such as Dungeness crab, Pacific herring, and English sole, combined with sporadic catches of some subtropical species, such as Pacific sardine and California grunion.

As we use at least six months' data to calculate the annual abundance indices of many species (often using data through October), most 2001 indices cannot yet be calculated. The two major exceptions are age-0 Dungeness crab (index period May–August) and age-0 Pacific herring (index period April–September).

The 2001 age-0 Dungeness crab abundance index is 10,012, which is the highest index since 1988 (the period of record is 1980–2001). By late summer, many of the age-0 Dungeness crabs were presumed to be in very shallow subtidal areas of San Pablo Bay, including the north bay marshes. The highest catches in the trawls were from Central Bay channel and Carquinez Strait stations.

The preliminary age-0 Pacific herring 2001 index is 319, which is slightly higher than the 2000 index; the 2000 and 2001 indices are the highest since 1986. In 2000 and 2001, the Central Bay stations had the highest catches of age-0 Pacific herring overall. In 2001, a larger percentage of the total catch of Pacific herring was from South and San Pablo bays than in 2000.

2001 Delta Smelt and Splittail Transportation and Release

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Since 2000 we've conducted an extensive literature search, exploring all aspects of handling and transport of fishes, including aeration techniques, water circulation techniques, history of fish transport, and use of anesthetics to improve survival.

The 2001 literature review focuses on primary and secondary fish stress indicators such as cortisol, glucose, and lactate found in blood plasma after exposure to stressors. The literature review is being used to design pilot experiments. Pilot physiology experiments will evaluate the effect of the John E. Skinner Delta Fish Protective Facility (Skinner) in Byron, California, on stress indicator levels in select fish (delta smelt, splittail, and other species that are endangered, threatened, or of special concern).

A series of transport and handling mortality experiments were conducted at Skinner from March through June of 1999 and April through July of 2000. During the experiments various juvenile species including splittail, American shad, delta smelt, longfin smelt, and other species were used to test handling losses independently of transport losses. After the experiments, fish were placed into 300-gallon recovery tanks to observe mortality. Fish mortality counts were recorded immediately following the experiments, at 24 hours, and at 48 hours. The sample size for these experiments varied between 50 and 100 fish. Dissolved oxygen, temperature, and visibility data were also recorded. Analysis of this data is underway.

In May 2001 transport and handling experiments were postponed temporarily, along with pilot experiments to sample fish stress indicators found in the blood plasma using newer blood sampling technology. These experiments resumed in July. The Roche Accu-Check™ handheld blood glucose meter and the Roche Accusport™ handheld blood lactose meter were tested for their efficacy in obtaining post-test recovery (48 hours post experiment) levels of blood glucose and lactate in threadfin shad about 60 mm long. The methods developed during the pilot study may be used in future studies to improve fish survival during transport, handling, and release at Skinner and other fish facilities.

Upper Estuary Chinese Mitten Crab Research Projects

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We focus on the Chinese mitten crab in the Sacramento-San Joaquin Delta with two research projects. With one project we investigate the effects of mitten crabs on the benthic invertebrate community and with the other we evaluate mitten crab habitat use.

We are evaluating the effects of the Chinese mitten crab on the benthic invertebrate community using an enclosure–exclosure study. We began this study in May 2001 and will continue through June 2002. In each trial, five enclosures containing two crabs each act as the experimental group and five exclosures containing no crabs act as a control group. The enclosures and exclosures remain in place for approximately 12 to 14 days and are set and retrieved during minus tides. To determine the effects of the crabs on the benthos, substrate core samples (containing benthic invertebrates) are taken for each treatment (enclosures and exclosures) and from random areas outside of these treatments both before and after the trial. Two study sites were selected to conduct these trials—Sherman Lake and Franks Tract. Starting in September 2002 the number of replicates of enclosures and exclosures will be increased from five to six. Initial processing of the core samples for invertebrates has generated four major groups, amphipods (various species), polychaetes and oligochaetes, clams (predominantly *Corbicula fluminea*), and chironomids. Further sorting and identification of individual specimens from each core sample will begin in October 2002 and will result in a detailed species list.

In addition to the enclosure–exclosure study, we are conducting a qualitative laboratory exercise to examine basic mitten crab feeding behavior. For this element we have re-created a “natural setting” inside laboratory aquariums using sediment (15 to 20 cm), aquatic vegetation (primarily *Egeria densa*), water, and crabs taken from Sherman Lake. Feeding behavior for the first 18 hours is documented visually using a digital camcorder. During each exercise we record crab activity under both lighted and dimly lit conditions. we will review videotapes from each exercise and document pertinent information. Our objective for this exercise is to examine basic feeding behaviors such as depth of feeding, preference for vegetation or invertebrates, preference of invertebrate prey species (especially clams), competition between individual crabs, and diel feeding activity. The first exercise was conducted in September 2001, additional exercises were conducted in October 2001, and more are scheduled for spring 2002.

We sampled a variety of habitats to determine the Chinese mitten crab’s habitat use of the Sacramento-San Joaquin Delta. Crabs were collected with an artificial substrate trap (referred to as a “crab condo”) and a baited trap (for Methods, see Veldhuizen and Corcoran 2000). The sampling effort was divided between several habitat categories: shallow (0 to 2 m) areas with and without vegetation, mid-depth (2.5 to 5 m) areas, and deep (5 m and over) areas. Sampling occurred from February 2000 through July 2001. Sampling with the baited trap was ineffective: only eight crabs were captured from 1,011 samples. Sampling with the crab condo was more effective: 206 crabs were captured from 278 samples. Crabs ranged in size from 8 mm to 58 mm carapace width (CW); the average size was 28 mm CW. The highest catches occurred from July through October. Initial results indicate crabs under 30 mm CW occur in all habitat types but are most common in shallow vegetated areas with natural or riprapped banks. Crabs 30 mm CW and larger appear to be evenly distributed among all sampled habitat types. We are scheduled to complete a study report by December 2001.

Reference

Veldhuizen T, Corcoran D. 2000. Chinese mitten crabs habitat use study. IEP Newsletter 13(2):6.

Mysids and Zooplankton

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Mysid shrimp abundance for summer 2001 was one of the lowest on record (1968–2001). The maximum *Neomysis mercedis* density was 1.1 m^{-3} near Rio Vista in June and none were collected in July or August. *Acanthomysis bowmani* was most abundant between Chipps Island and Rio Vista, where the maximum density reached 116 m^{-3} in June. *Acanthomysis bowmani* densities remained high in the same area throughout the summer, but overall abundance was lower than in 2000.

The changes in calanoid copepod densities from summer 2000 were mixed. Densities of *Pseudodiaptomus forbesi* (exotic), *Acartia* (native), and *Diaptomus* (native) were lower than in 2000, *Eurytemora* (exotic), and *Acartiella* (exotic) densities were higher, while *Sinocalanus doerri* densities were essentially the same in 2001 as in 2000. *Pseudodiaptomus forbesi* summer abundance was the lowest since 1989. It was most abundant near Rio Vista and in the San Joaquin river, with maximum densities of 2,482 m^{-3} at Rio Vista in June and 2,307 m^{-3} at Stockton in July. Typically, *Acartia* was found primarily in San Pablo Bay where the density reached 824 m^{-3} in August. *Sinocalanus doerrii* maxima occurred from the upstream end of the entrapment zone to Rio Vista and peaked at 2,243 m^{-3}. *Eurytemora* abundance peaked in Disappointment Slough at 827 m^{-3}. *Acartiella*, which has been declining since 1998, increased its abundance in July and August from a June maximum of 8 m^{-3} in the entrapment zone to 981 m^{-3} near Rio Vista in August. *Diaptomus* was collected only in June in the lower San Joaquin River where the maximum density was 48 m^{-3}.

Although native cyclopoid copepods had lower abundance this year, overall cyclopoid abundance was higher because of increased *Limnoithona tetraspina* abundance. The introduced cyclopoid *L. tetraspina* was again the most abundant copepod in the Delta. In all three months the region of *L. tetraspina* abundance was centered around the downstream end of the entrapment zone. Densities at that location were 4,495 m^{-3} in June, 71,943 m^{-3} in July, and 55,495 m^{-3} in August. *Acanthocyclops vernalis* (native, formerly *Cyclops vernalis*) densities were lower than in 2000. *Acanthocyclops vernalis* declined from a high of 436 m^{-3} at Stockton in June to zero by August. Abundance of *Cyclops* spp. for summer 2001 was one of the lowest recorded.

The densities of all species of cladocera were low in the summer of 2001. The peak abundance region for all cladocera was at Stockton, except for June, when *Bosmina* abundance was higher in Suisun Slough. Cladoceran abundance for summer was highest in July when *Bosmina* density was 5,313 m^{-3}, *Daphnia* density was 4,469 m^{-3}, *Diaphanosoma* density was 2,163 m^{-3}, and the density of all other cladocera was 1,009 m^{-3}.

Every rotifer species increased in abundance from summer 2000. Rotifers were located primarily in the western Delta in Disappointment Slough, the San Joaquin River, and the Sacramento River above Chipps Island.

Shallow Water Predator-Prey Dynamics Study

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We are assessing the shallow water habitat use, diet composition, and prey selection patterns of striped bass *(Morone saxatilis)*, Sacramento pikeminnow (*Ptychocheilus grandis*), largemouth bass (*Micropterus salmoides*), and channel catfish (*Ictalurus punctatus*). This includes an explicit test of the null hypothesis that prey selection by piscivorous fish is based on prey availability (in other words, prey relative abundance). We sample once per month at five sites, described in detail below. All sampling occurs from late afternoon to just after sunset using a 30-m by 1.8-m beach seine with 3.2-mm mesh, and a 60-m by 2.4-m gill net with random panels, varying from 51-mm to 102-mm stretch mesh.

Sherman Lake. Sherman Lake was formed in 1869 when floodwaters inundated Sherman Island. The westernmost portion of the island was never reclaimed. Sherman Lake is part of the confluence of the Sacramento and San Joaquin rivers, but our sampling site is on the Sacramento River (north) side. The sample site has broad sandy shoals overlain with silt in some places. These include the largest shoal areas of any of our sampling sites. Deeper channels separate small islands, which are the remnants of the former north levee. Tules and *Arundo donax* dominate the shoreline vegetation. Submerged aquatic vegetation (SAV) is extremely sparse. The water is very turbid, with Secchi disk depths rarely, if ever, exceeding 20 cm.

Decker Island. Decker Island was formed when the U.S. Army Corps of Engineers dredged the Sacramento Deep Water Ship Channel. Horseshoe Bend, which passes along the eastern and southern edges of Decker Island is the original Sacramento River channel. In Horseshoe Bend, Decker Island's northeast shoreline has a contiguous beach extending about 0.5 km. The beach is a narrow (<10 m) sandy shoal at the upstream end that grades in a downstream direction into a broader shoal, including silty substrates and a thin strip of SAV (mostly *Egeria densa*). At high tides, sparse riparian vegetation provides some overhead cover. Secchi disk depths are usually about 20 to 40 cm.

Liberty Island. Liberty Island, the Delta's newest permanently flooded island, sits at the base of Yolo Bypass. Levees were not rebuilt in the latter 1990s, after repeated inundation during high outflows in 1995–1999. Liberty Island is generally <3 m deep. We sample along the eastern levee, where substrates range from silt–sand to gravel to large clumps of clay. The site is tidally connected to Prospect Slough, the base of the Yolo Bypass toe drain. There is no SAV, but underwater cover exists from remnant orchards, roads, and farming equipment. The water is extremely turbid, with Secchi disk depths always less than 20 cm.

San Joaquin River. We sample the mainstem San Joaquin River along the north shore of Medford Island. Wadable shoal widths vary from about 10 to 30 m (depending on tide and specific site) before depth increases abruptly to >10 m in the shipping channel. Sandy beaches of varying width are interspersed with tule and *A. donax*. On some beaches, growth of SAV (mostly *E. densa*) and benthic filamentous algae is substantial, but others represent open habitat. Water clarity is almost always higher than at the Sacramento River sites. Secchi depths recorded in 2001 have ranged from about 25 to 55 cm.

Mildred Island. Mildred Island, now a large, tidally influenced lake within the central Delta, was formed during flooding in 1982. Most of the island's rim is wadable depth, but growth of terrestrial (*A. donax*), emergent aquatic (tule), SAV (mostly *E. densa*), and floating aquatic vegetation restrict the amount of habitat we can sample with a seine. Water clarity within the island is substantially higher than at other sites, with Secchi depths always exceeding 50 cm.

Predator Fish Observations

Predatory fishes are regularly collected at all five sampling sites. Most are small individuals (< 300 mm, or about 1 foot in length) (Table 1). But even at these sizes, juvenile and small adult fish are the major diet component. The catch data in Table 1 have not been corrected for volume or time sampled, but it is clear that young striped bass are considerably more abundant in shallow water habitats than other piscivorous species; however, spatial distributions are important. For instance, largemouth bass are the most commonly collected shallow water piscivore in the San Joaquin side of the Delta. Fieldwork will continue through October 2001, then efforts will switch to quantifying gut contents from the 2001 collections.

Table 1 Numbers of piscivorous fish collected from March-August 2001

	striped bass		*pikeminnow*		*largemouth bass*		*channel catfish*	
Sampling locations	*100–299 mm*	*300+ mm*	*100–299 mm*	*300+ mm*	*100–299 mm*	*300+ mm*	*100–299 mm*	*300+ mm*
Sherman Lake	239	8	34	7	4	0	0	0
Decker Island	52	1	36	2	8	1	0	0
Liberty Island	63	1	9	0	0	0	1	2
San Joaquin River	14	1	43	0	46	5	3	4
Mildred Island	32	10	0	0	35	3	12	10
Total	400	21	122	9	93	9	16	16

Sherman Island Agricultural Diversion Evaluation

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This element evaluates the relative abundance and species composition of fishes entrained in parallel diversion siphons in Horseshoe Bend on the lower Sacramento River. In particular, we are emphasizing the effects of tidal and diel cycles on fish entrainment. The Horseshoe Bend facility consists of two, screened, 24-inch diversion pipes and one unscreened 24-inch pipe. One screened and the unscreened siphon were sampled simultaneously using modified fyke nets (1600 μm mesh) that fit completely over the outfall side of the pipes so that all of the water coming through the siphons is filtered by the nets before entering the irrigation canal.

Last year we conducted a sampling “blitz”—a 43.5-hour period of continuous sampling—on July 12–14. A summary of last year’s results were reported on page 11 of the fall 2000 issue of the *IEP Newsletter*. This year we conducted another blitz on July 9–11, with sampling timed to coincide with high tide periods around sunset. This contrasts with last year’s sampling, during which high tides occurred in the middle of the night. We have completed larval fish identification and data entry is underway.

North Bay Aqueduct and 20-mm Surveys

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North Bay Aqueduct Survey

The North Bay Aqueduct (NBA) larval fish survey was completed on July 15, 2001. A total of 44,557 fish was collected over the five-month survey. The majority of the catch included prickly sculpin (33.9%), striped bass (27.5%), and threadfin shad (20.7%), a similar composition observed last year. Delta smelt catch totaled 574 fish this season, almost doubling the catch from last year (309), setting a new NBA Survey catch record. Longfin smelt also were abundant early in the season with 2,282 collected through March and totaling 2,388 by the end of the season.

The increased presence of larval delta smelt in the north Delta, in particular Barker Slough, triggered pumping restrictions for the North Bay Aqueduct Pumping Facility. On nine separate sampling dates between April 7 and May 25, the delta smelt weighted average triggered the criteria. When the weighted average of delta smelt catch from Barker Slough is equal to or greater than 1.0, NBA pumping is restricted to a five-day running average of 65 cfs. On two of these dates the pumping facility was above the 65 cfs average and had to reduce pumping when the catch was reported. For on-line information about the NBA Survey, see http://www.delta.dfg.ca.gov/data/nba/2000.

The 20-mm Survey

The 20-mm larval and juvenile fish survey was completed on July 9, 2001. The final survey was cut short due to mechanical problems with boats and was not continued. As a result, only part of the south Delta was sampled. Moderate catches of young-of-the-year delta smelt first appeared in the central Delta, with limited catches in the south and north Delta. This population consisted of a few cohorts, which appeared to remain in the lower San Joaquin River between Jersey Point (station 809) and the mouth of Potato Slough (station 815) through most of April and May. By the end of the season most delta smelt were located in the lower Sacramento River between Sherman Lake (station 703) and Threemile Slough (station 707). A total of 1,019 delta smelt was collected this season.

Take levels at the SWP and CVP never reached a “red light” level like last year, but did reach a “yellow light” level of concern from May 21 through June 5. The relative low abundance in the south Delta and low pumping rates reduced the salvage at both facilities. For on-line information about the 20mm Survey, see http://www.delta.dfg.ca.gov/data/20mm/2000.

Real Time Monitoring Activities

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The 2001 field season (March 19 to June 30) of the Real Time Monitoring Program (RTM) was the most varied in its seven-year history. We continued activities from the 2000 season (described below), conducted evaluations of three different gears, and began preparing a programmatic review. The gear evaluations are intended to improve monitoring capabilities. The following activities were continued from the 2000 season:

1. Rapid data reporting from the U.S. Fish and Wildlife Service (USFWS), the State Water Project (SWP), and the Central Valley Project (CVP) through the RTM web page.

2. Kodiak trawling at Mossdale with Department of Fish and Game (DFG), Region 4, to monitor emigrating San Joaquin River chinook salmon and splittail. Data were reported through the RTM web page (see address below).

3. Light trapping in the Delta for larval delta smelt. Some preliminary results from light trapping were provided through the RTM web page and Data Analysis Team.

We conducted three gear evaluations:

1. A townet similar to the gear used by the DFG young-of-the-year (YOY) striped bass midsummer townet survey (TNS), which conducted sampling at six stations in the central and south Delta.

2. A larger Kodiak net (the "Super Kodiak," with 6 ft by 40 ft dimensions as opposed to 6 ft by 25 ft).

3. A larger 20-mm net (the "Super 20" with a mouth area of 2.25 m^2 compared to 1.5 m^2 for the net currently used in the DFG 20-mm Survey).

Results from Mossdale Kodiak trawling, USFWS, SWP, CVP and some preliminary results from light trapping can be viewed on-line at http://www.delta.dfg.ca.gov/data/rtm2001/.

Juvenile Salmon Monitoring

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The U.S. Fish and Wildlife Service Stockton Office continued monitoring for juvenile salmon and other resident species with summer background sampling.

In the Sacramento midwater trawl, a total of 32 fall-run chinook smolts was captured from July 1 through July 13, when boat problems and the lack of a replacement boat caused sampling to be curtailed. When sampling resumed, another four fall-run chinook smolts were captured between July 27 and September 14. Catch per cubic meter in the trawl was the highest since 1995 during the July through mid-September period. There were also two yearling late-fall chinook and one winter-run fry (38 mm, September 10) in the Sacramento trawl for the same period. In the Mossdale Kodiak trawl, one fall-run chinook smolt was captured on July 13. The Chipps Island midwater trawl captured 36 fall-run smolts, three yearling late-fall chinook, and eight adult chinook between July 3 and September 13.

Two wild steelhead were captured during the period: one adult at Chipps Island on August 14, and one juvenile (258 mm) in the Sacramento trawl on September 19.

Fyke trapping for adult salmonids began in September with two traps deployed along the Sacramento River upstream of the Delta Cross Channel (DCC), three traps in the DCC, and two in Georgiana Slough.

On September 10, the Mossdale Kodiak trawl was suspended due to low flows. We will resume trawling when the flows increase.

For a review of the juvenile salmon monitoring program on-line, see http://www.delta.dfg.ca.gov/usfws/.

Splittail Investigations

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Future planning, proposal writing and review, and report writing dominated the work for the summer quarter. An IEP proposal was submitted to investigate the movements of splittail larvae in the Sacramento River and Sutter Bypass and determine what cues might stimulate their emigration from the floodplain. In addition, we propose to assist DFG Region 2 personnel in monitoring a screw trap in the lower Sutter Bypass. In past years this gear has been very successful in documenting splittail use of and emigration from the bypass.

A report on splittail larval abundance and distribution based on striped bass egg and larva sampling, 1988–1994, was sent out for IEP review in late September. Additional reports concerning juvenile habitat, adult movements on the spawning ground and spawning location, and young-of-the-year abundance based upon the USFWS Beach Seine Survey will be released serially through the fall.

Under Jan Paxio's direction, we've completed three independent readings of splittail dorsal and pectoral fin-rays (about 40 sets of each). Jan is preparing to complete a report by late fall 2001. Clarity and appearance of annuli varied substantially from fish to fish. Even in these calcified structures, later annuli of older fish appeared less distinct and were possibly not distinguishable in some fish. We're still on track to complete this report in late fall.

Finally, some time has been devoted to responding to the re-opened comment period on the federal listing of splittail as a threatened species. As part of this response, we have developed the means to calculate age-specific abundance indices for splittail from the Fall Midwater Trawl Survey: now age-1 and age-2+ (adult) abundance indices are available. Also, in collaboration with Mike Chotkowski (USBR), we have developed a regression model to address splittail abundance trend analysis that incorporates hydrology. The model uses a surrogate for floodplain inundation (the number of days of total inflow >55,000 cfs) and year as factors to investigate trends in age-specific abundance. We expect to report more about this analysis in the future.

Sturgeon Tagging

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We began sturgeon tagging on August 6, 2001, coincident with sampling with a 200-fathom drift trammel net in San Pablo Bay. This effort began a month earlier than in previous years to attempt to capture additional green sturgeon under a contract with the University of California, Davis (UCD). Researchers at UCD required additional green sturgeon samples for studies of genetic diversity, movement and spawning migration patterns, and reproductive development. As green sturgeon catches decreased substantially between September and October in past tagging efforts, we thought our normal fall tagging may be sampling the last part of a summer migration into the estuary or the end of post-spawning emigration or both. If either was true, tagging in August would catch more green sturgeon than in later months.

Our thoughts proved to be correct. We captured 23 legal-sized (117 to 183 cm total length) green sturgeon and 208 legal-sized white sturgeon in August, a ratio of about 10 green sturgeon to 100 white sturgeon. A total of 22 green sturgeon and 197 white sturgeon was tagged in August. An additional 15 legal-sized green sturgeon (all 15 tagged) and 148 legal-sized white sturgeon (140 tagged) were caught (nine sampling days) in September.

Sublegal green sturgeon have also been relatively abundant in our catches this year. In August, we caught 99 sublegal green sturgeon and 70 sublegal white sturgeon, a ratio of 140 green sturgeon to 100 white sturgeon. This catch ratio was maintained in early September, when 48 sublegal green sturgeon and 34 sublegal white sturgeon were caught. No sublegal fish were tagged.

Comparison of these data with past data on relative abundance of the two sturgeon species is difficult because of the different periods sampled. A comparison of catches this year in the first half of September with catches in the full month of September in past years provides some information. This year's September ratio of green to white sturgeon (10:100 for legal fish and 140:100 for sublegal fish) suggests green sturgeon are relatively more abundant than in most other tagging years. In past years, the legal-sized ratio has ranged from 0:100 in 1994 to 5:100 in 1990. Except for 1974, when the ratio for sublegal fish was 270:100, this ratio has ranged from 0.3:100 in 1993 to 54:100 in 1985.

An unusual tag recovery from a striped bass is worth mentioning. On September 14, a striped bass tag was found in the trammel net that had been attached to a 3-year-old, 40-cm male fish in April 1972. Either this tag was laying on the bottom of San Pablo Bay and became entangled in the net or it was on the fish, became entangled, and the fish pulled free, leaving the tag behind. In the latter case, this 32-year-old striped bass would be the oldest we have (almost) encountered.

Townet Survey

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The Summer Townet Survey (TNS) has been used to index young striped bass abundance in the Sacramento-San Joaquin Delta since 1959 (Chadwick 1964; Turner and Chadwick 1972) and more recently delta smelt abundance (Stevens and others 1990; Moyle and others 1992).

Three biweekly surveys were completed during the 2001 TNS: survey 1 (June 12–16), survey 2 (June 26–29), and survey 3 (July 10–14). A fourth survey was attempted to expand delta smelt coverage, but was only partially completed due to boat problems. Thirty-two stations were sampled during each survey, with the exception of survey 1, when three stations were not sampled due to boat problems.

Results reported are restricted to young-of-the-year (YOY) fish. For striped bass, YOY included all bass ≤99 mm FL. For delta smelt, YOY included all smelt ≤69 mm FL. No striped bass >99 mm FL and only six delta smelt >69 mm FL were caught during surveys 1–4. Three of the delta smelt >69 mm FL were from survey 4.

Striped Bass

The TNS calculates an annual abundance index for striped bass when the average size is 38.1 mm FL (Chadwick 1964; Turner and Chadwick 1972). In 2001, this size was attained between surveys 2 and 3 in 2001 (Table 1). The annual index of abundance was "set" at 3.6 on July 6, 2001. Although the 2001 index is lower than the 2000 index of 5.5, it is still higher than any other year since 1995 (Figure 1).

Table 1 Mean length, sample size, and survey indices for striped bass and delta smelt during townet surveys 1–3, 2001

Species and variable	*Survey 1*	*Survey 2*	*Survey 3*
Striped Bass			
Mean length (mm FL)	20.2	31.0	43.4
N	719	222	69
Survey index	20.1	6.2	2.3
Delta Smelt			
Mean length (mm FL)	29	34	38
N	83	89	135
Survey index	3.4	3.6	5.5

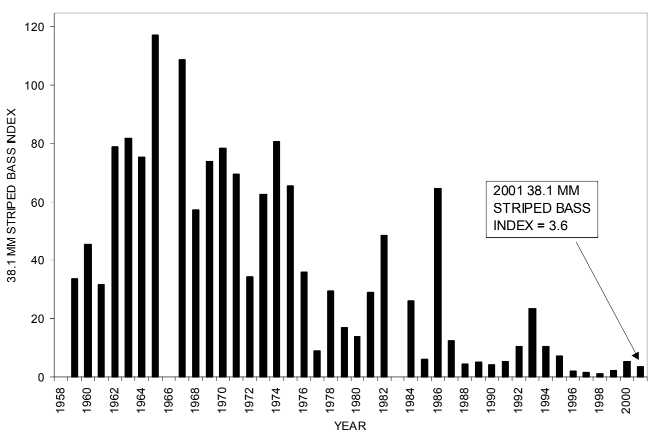

Figure 1 Annual striped bass townet index, 1959–2001

Distribution of striped bass during the 2001 TNS showed movement downstream over time (Table 2). Surveys 1 and 2 showed the highest numbers of striped bass in the Sacramento and San Joaquin rivers. Distribution during survey 3 was almost equal between the Sacramento River, the San Joaquin River, and Suisun Bay; there was a 23% increase in the Suisun Bay index from survey 2 to 3.

Table 2 Percentages of survey index by area for striped bass and delta smelt for townet surveys 1–3, 2001

Species and area	*Survey 1*	*Survey 2*	*Survey 3*
Striped Bass			
Montezuma Slough	1.0	10.0	6.0
Suisun Bay	9.0	10.0	33.0
Sacramento River	47.0	50.0	24.0
San Joaquin River	31.0	23.0	30.0
East Delta	7.0	3.0	1.0
South Delta	5.0	5.0	5.0
Delta Smelt			
Montezuma Slough	0.1	0.1	0.3
Suisun Bay	1.2	9.5	16.1
Sacramento River	77.3	88.2	76.0
San Joaquin River	20.2	2.2	7.7
East Delta	1.2	0.0	0.0
South Delta	0.0	0.0	0.0

Delta Smelt

The annual abundance index for delta smelt is the average of the survey indices for the first two surveys. The 2001 delta smelt index is 3.5; which is lower than in 1999 (11.9) and in 2000 (8.0) (Figure 2).

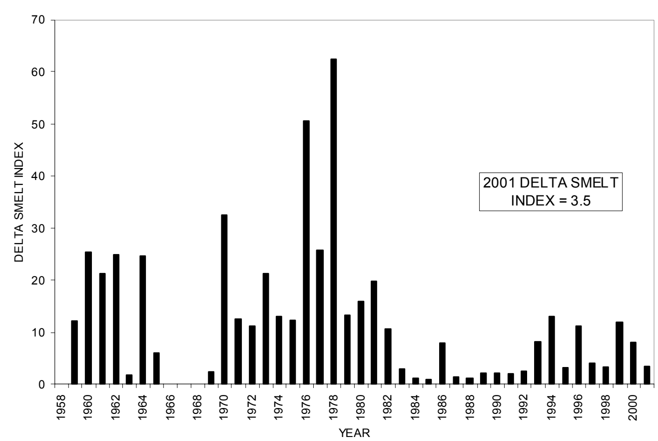

Figure 2 Annual delta smelt townet index, 1959–2001

Distribution of delta smelt showed little variation throughout the three surveys, with the majority caught just above the confluence in the Sacramento River (from 76% to 88% of the total index). For survey 4, all of the stations east of the confluence were sampled before the boat failure. Delta smelt were present at nearly all the same stations as in the previous surveys, with 90% in the Sacramento River. More delta smelt (183) were caught during survey 4 than each of the first three surveys.

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Delta Resident Shoreline Fish Sampling

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The new Delta Resident Fishes Monitoring Element was started April 3, 2001. This survey consists of sampling fifteen 0.5-km-long randomly selected shoreline sites throughout the Delta each month using a boat-mounted electrofisher. A new random site selection occurs each month and is stratified by area so that four sites are sampled in the east and central Delta, two sites are sampled in the north and west Delta, and three sites are sampled in the south Delta. This stratification of effort corresponds approximately with the relative abundance of resident fishes in each area. Shoreline habitat types and chemical and physical variables are recorded for each site. A total of 2,832 fish from 32 species and 14 families was captured from July 2, 2001 to August 24, 2001. Of those fish, 4% were native species and 96% were introduced. Stomach contents were collected from up to five individuals per species per site using gastric lavage or dissection. A total of 879 stomach samples from 32 species was also collected. Identification of these stomach contents is now underway to allow description of food habits and trophic interactions of the shoreline fish community. Of the stomachs sampled thus far, 16% were empty. The sampling for September is not complete as of this writing, so those data are not yet available. In addition, anglers have recaptured and reported 69 of the 408 largemouth bass that were tagged from April 3, 2001, to June 13, 2001. These data will be used to estimate largemouth bass mortality rates in the Delta.

IEP Environmental Monitoring Program Review

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As previously reported (*IEP Newsletter* winter 2001), the IEP Environmental Monitoring Program (EMP) is currently undergoing a programmatic review. This review is intended to appraise, redesign and reinvigorate this 30-year old program to meet the challenges and information needs of the 21st century. The review is conducted using a multi-tiered approach involving a core group of agency scientists, invited technical experts working in four subject area teams, stakeholder representatives participating in large, all-participant meetings, and the IEP Science Advisory Group (SAG). In the first seven months of this review, two successful all-participant meetings and numerous small team meetings have taken place. At this time, the subject area teams have concluded reviews of the water quality, zooplankton, phytoplankton, and benthos components of the EMP. Synthesized results from these reviews and emerging plans for a revised monitoring program and special studies will be presented and discussed at the third and final all-participant meeting at the SFSU Romberg–Tiburon Conference Center on November 14, 2001. In the final phase of the review, the IEP SAG will review the existing program and the results from the subject area team reviews and all-participant meetings. Their recommendations will be worked into a final draft plan. This plan will be presented at the 2002 IEP Workshop at Asilomar. DWR and USBR agency review and submission to the SWRCB Executive Director are also expected to occur in 2002. Implementation of program revisions will begin in January 2003. For information please contact Anke Mueller-Solger, DWR-ESO (amueller@water.ca.gov) or see the EMP web page at http://iep.water.ca.gov/emp/.

NEWS FROM AROUND THE ESTUARY

Eurytemora affinis is Introduced

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The origin of *Eurytemora affinis*, an important copepod food item for young and small fishes in the estuary, has been the subject of some speculation. This copepod has a circumglobal distribution—it is found on both coasts of North America and Eurasia and on the Gulf coast of the United States. Its distribution has implied successive introductions from an undetermined source region. Some scientists believe the San Francisco Estuary population was introduced from New Jersey by way of railroad tank cars that carried striped bass here in the late 19th century.

Recently, Dr. Carol Lee of the University of Wisconsin, published a paper on the phylogeny of *Eurytemora affinis* (Lee 2000). Using DNA analysis, she determined that the species probably originated in an ice-free Arctic about 5 million years ago. Then, as the climate cooled, populations moved south onto both coasts of Asia and America and branched into a group of morphologically indistinguishable and reproductively isolated sibling species. Dr. Lee has identified two clades of the *E. affinis* species complex in North America: the North Pacific and the North American. The latter is composed of three subclades: North Atlantic, Atlantic, and Gulf. Significantly, two of the West Coast's populations, one from Gray's Harbor, Washington, and one from the San Francisco Estuary, belong to the Atlantic clade.

In e-mail communications, Dr. Lee said that she believes that the two West Coast populations of the Atlantic clade originated on the East Coast of North America. They are genetically closest to specimens from Martha's Vineyard and are separated from them by only two mutations out of 652 base pairs in the cytochrome oxidase I (COI) gene. However, she had no specimens from New Jersey, the source region of striped bass, to compare with them. On the other hand, the transplanted Atlantic clade populations are separated from the native North Pacific clade populations by 17% to 19% differences in base pairs in the COI gene.

The speculation that *E. affinis* was introduced is, therefore, confirmed. While it is theoretically possible that a North Pacific clade *E. affinis* is also present, a second clade should reveal its presence by having different population maxima in time, space, or salinity. No such differences have been observed. This means that before the introduction there was no native copepod species abundant in the low salinity zone (0.6 to 6.0 psu) of this estuary. It could only have been inhabited by stragglers of the marine *Acartia* spp. and of the freshwater *Diaptomus* and *Cyclops* groups. When fish culturists introduced striped bass in the estuary, they also unknowingly provided them with a food source that very likely enabled them to become established. But more—*E. affinis* was formerly the most important food item of delta smelt (*Pseudodiaptomus forbesi* has replaced it). What did delta smelt eat before *E. affinis* arrived and was the delta smelt population as abundant before the advent of *E. affinis* as it was during the 1960s? These questions can not be answered but make us realize that supposedly ideal feeding conditions for both native and introduced fishes may have been only relatively recently created by the inadvertent introduction of *E. affinis*.

Reference

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Status of the Chinese Mitten Crab and Control Plans at the State and Federal Fish Facilities

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Each fall, Chinese mitten crabs (*Eriocheir sinensis*) migrate downstream from freshwater rearing areas, such as the Delta and Sacramento and San Joaquin rivers, to spawn in the saline waters of Suisun and San Pablo bays. The migration begins in late August and continues through December. The majority of crabs migrates early September through mid-October.

During their migration through the South Delta, mitten crabs mistakenly head “downstream” toward the State Water Project (SWP) and Central Valley Project (CVP) Delta export and fish collection facilities. It is unknown why the crabs move into the facilities, but it is possible that the change in flow patterns, resulting from SWP and CVP operations, are substantial enough to influence the crab’s migration. Based on data from the past four years, we expect mitten crabs to impede operations at the fish collection facilities mainly during September and October. Mitten crabs are present in low numbers at the facilities in late August, November, and December, but their effects during these months is relatively minor.

This year, Chinese mitten crabs began entering the USBR’s Tracy Fish Collection Facility (TFCF) in late August (Figure 1). Numbers remained low (under 200 crabs per day) through September 15, then sharply increased during late September to over 1,300 crabs per day. Mitten crabs began entering DWR’s Skinner Delta Fish Protection Facility (SDFPF) in low numbers (less than 60 per day) in early September and increased to about 300 per day by late September. Data from the previous three years indicate there is a one to two week delay between the appearance of crabs at TFCF and SDFPF. As of this writing, mitten crab numbers at SFF may exceed 1,000 crabs per day by mid-October.

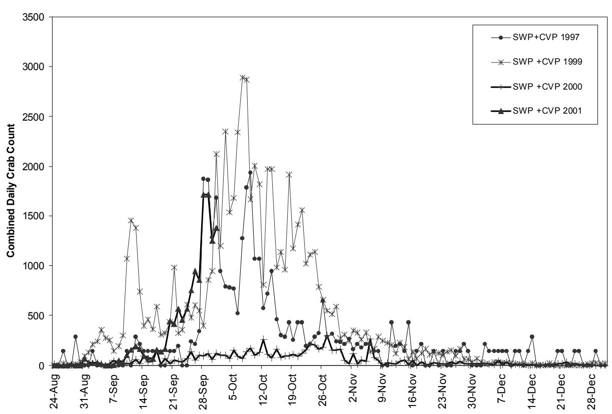

Figure 1 Combined daily Chinese mitten crab counts at TFCF and SDFPF, 1997, 1999–2001

The combined abundance of mitten crabs at both facilities is approaching the level observed in 1999 (see Figure 1). In fall 1999, combined mitten crab counts remained elevated from September 29 through October 24. During this period, crab counts at the fish facilities ranged from 792 to 2,892 crabs per day and averaged 1,564 crabs per day. Daily crab counts at the fish facilities have already surpassed the numbers observed in 1997 and 2000 (Figure 1). In 1997, combined mitten crab counts reached nearly 2,000 crabs per day several times during the first half of October. By mid-October, crab counts dropped below 500 crabs per day. In 2000, combined mitten crab counts did not exceed 300 crabs per day for the entire season. Daily mitten crab counts were ten times higher in September 2001 compared to the daily counts of September 2000. Despite an increase in crab numbers this year, crab counts are still substantially below those of 1998 (Figure 2). In 1998, combined daily crab counts remained at or above 1,000 from August 28 to November 15, exceeded 10,000 crabs per day for 35 days, and peaked at 51,292 crabs per day in late September.

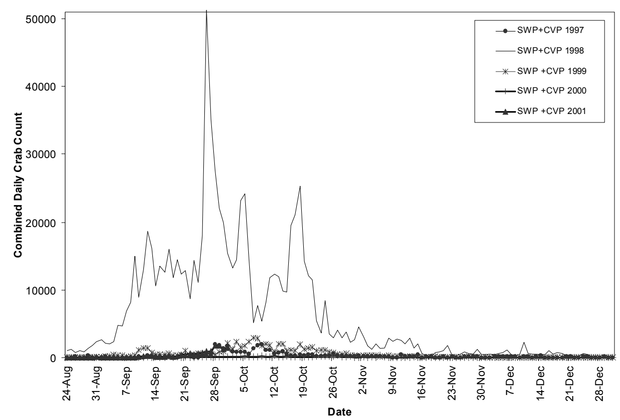

Figure 2 Combined daily Chinese mitten crab counts at TFCF and SDFPF, 1997–2001

The large and prolonged influx of mitten crabs hampered fish salvage operations at both facilities in 1998 (Siegfried 1999; White and others 2000). In response, USBR and DWR developed devices to reduce the number of crabs entering the collection facilities. USBR installed a travelling screen in the secondary channel to remove crabs before they entered the holding tanks (Siegfried 1999; White and others 2000). This year, USBR began operating the travelling screen September 19. USBR is only allowed to operate the travelling screen when the daily crab count is at or above 200 crabs per day. The travelling screen was modified since last year. A conveyor belt replaced the auger, which allows counts of all crabs removed by the screen. However, the modification reduced the efficiency of the travelling screen. Last year, the travelling screen was about 85% effective in removing crabs from the secondary channel; this year it is less than

50% effective. USBR staff is making further modifications to increase screen efficiency.

DWR is still developing its mitten crab control structure for SDFPF. A k-rail barrier was installed in the intake channel, which funnels the crabs toward a trap. However, no crabs have been trapped since the k-rails have been used. Last year, DWR staff proposed different configurations of the k-rail barrier, such as a different angle relative to the water flow or a "V" formation. The trap was also modified, but was finished too late for testing. This year is a good year to test the barrier configurations and the new trap, given the high number of crabs occurring at the SDFPF.

DFG recommends installing the k-rail barrier at SDFPF before crab numbers reach levels detrimental to salvaged fish. When the daily crab count at SDFPF reaches 1,000 crabs per day, the mitten crabs cause high fish mortality during the salvage process, especially in the hauling trucks. Members of the Fish Facilities Mitten Crab Project Work Team set a criterion for installation of the k-rail barrier: if the 3-day running average of the daily mitten crab count at TFCF exceeds 750 crabs per day for three consecutive days, DWR staff would begin installation of the k-rail barrier. Because mitten crabs reach TFCF one to two weeks before reaching the SDFPF, the criterion gives DWR staff one to two weeks to install the barrier before crab numbers reach 1,000 or more per day. This year the criterion was reached at the end of September. Mitten crab numbers increased sharply at the end of September at TFCF, causing the 3-day running average to exceed 750 for three consecutive days. Mitten crab numbers at TFCF remained above the established criterion in early October. However, staff in DWR's Operation and Maintenance Division (O & M) has postponed k-rail barrier installation until absolutely necessary because of the associated high cost.

O & M staff is proposing to wait until crab counts reach 750 at SDFPF before installing the k-rail barrier. They are currently organizing the necessary equipment and personal required for barrier installation, including a crane, the k-rails, and SCUBA divers. In the meantime, staff remove crabs from the holding tanks and collection bucket before the fish are deposited in the hauling trucks to limit crab-related effects. If needed, other preventive measures taken may include altering pumping operations to decrease attraction flows and increasing trucking frequency to reduce fish density and mortality in the hauling trucks.

Mitten crab numbers are expected to peak at both facilities in mid-October and decline by early November. However, a spike in crabs is expected at the fish facilities after the South Delta temporary barriers are removed, as was observed in previous years. The three temporary barriers are scheduled for removal by early November. SDFPF staff need to be prepared for this spike. Fortunately, few fish species of concern are entrained in the facilities at this time, especially in dry years. On average, 1 steelhead, 61 splittail, and no chinook salmon enter SDFPF during October in dry years. At TFCF, no steelhead, 9 splittail, and 6 chinook salmon enter the facility during October in dry years.

References

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DAYFLOW Program Update

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Introduction

Dayflow is a computer program developed in 1978 as an accounting tool for determining historical Delta boundary hydrology. Dayflow output is used extensively in studies initiated by DWR, DFG, and other state and federal agencies, universities, and consultants.

The Dayflow program presently provides an estimate of historical mean daily flows: (1) through the Delta Cross Channel and Georgiana Slough; (2) past Jersey Point; and (3) past Chipps Island to San Francisco Bay (net Delta outflow, Figure 1). The degree of accuracy of Dayflow output is affected by its computational scheme and the accuracy and limitations of the input data. The input data include the principal Delta stream inflows, Delta precipitation, Delta exports, and Delta gross channel depletions. These data include both monitored and estimated values as described in the Dayflow program documentation. Currently, flows are not routed to account for travel time through the Delta. All calculations involving inflows, depletions, transfers, exports, and outflow are performed using data for the same day.

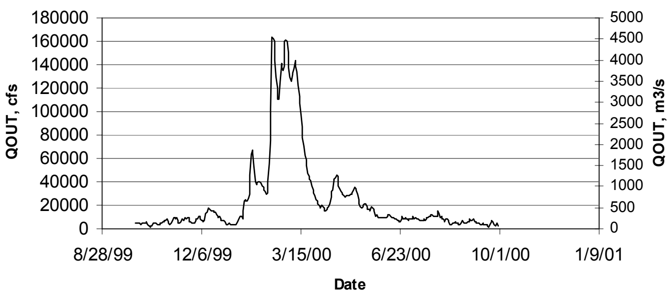

Figure 1 QOUT: Estimated total net Delta outflow past Chipps Island from Dayflow

The software used to perform Dayflow calculations was rewritten in Java in 2000. Input data are stored in a HEC-DSS file, and output is written to an ASCII file. This article describes improvements in the Dayflow program, including its output and website.

Dayflow output files were adjusted by correcting minor errors to output files for water years 1997–2000 and by modifying the computational scheme. Dayflow parameters and definitions (Table 1) also were adjusted. Specific adjustments to the parameters and the associated effects are described below.

Table 1 Dayflow parameter definitions

Parameter	*Definition*
QYOLO	Yolo Bypass addition to the Delta Water Balance
QTOT	Total Delta Inflow
QRIO	Sacramento River Flow Estimate Past Rio Vista
QOUT	Net Delta Outflow Estimates at Chipps Island
QEFFECT	Effective Western and Central Delta Inflow
QEXPORTS	Total Delta Exports and Diversions and Transfers
QMISDV	Miscellaneous Water Diversions and Transfers
QEXPIN	Export:Inflow Ratio
QEFFECT	Effective Western and Central Delta Inflow
QEFFDIV	Effective Percent Western and Central Delta Water Diverted
QCD	Net Channel Depletion
QSJ4SD	Amount of San Joaquin River water used in, or diverted from, the southern Delta

- Errors in the calculated values of QYOLO for water year 2000 were corrected. The values of QTOT, QRIO, QOUT, and QEFFECT changed as a result.
- The definition of QEXPORTS was modified to exclude QMISDV. The values of QEXPIN, QEFFECT, and QEFFDIV changed as a result. These changes affected only water year 1997 calculations.
- Errors in the calculated values of QEXPIN were corrected for water years 1997–2000.
- Errors in the calculated values of QCD were corrected for water years 1997–2000. The values of QEFFECT and QEFFDIV changed as a result. These changes affected only water year 1997 calculations.
- The definition of QSJ4SD was changed to include QMISDV. The values of QEFFECT and QEFFDIV for water year 1997 changed as a result.

In the future, we will continue to improve the Dayflow program as new direct flow measurement data become available. For example, the Dayflow computational scheme will be updated when flow monitoring begins in the Delta Cross Channel. The parameter QXGEO, an estimate of Georgiana Slough and Delta Cross Channel flow, will become obsolete and will no longer be used when Delta Cross Channel flow data become available.

As more direct flow measurements become available, the accuracy and reliability of Dayflow output will continue to improve. All Dayflow users are encouraged to replace their current output files with the updated files now available on-line at http://www.iep.water.ca.gov/dayflow, where additional modification details are available.

The Dayflow website has been redesigned to make the documentation more accessible to users. The documentation has been rewritten to improve the consistency of the Dayflow parameter nomenclature, to include changes in Dayflow parameter definitions, and to describe current procedures for creating Dayflow output. Documentation is now available in Adobe Acrobat PDF format as well as HTML.

In the future, a greater effort will be made to keep Dayflow users informed of any changes to the website, including documentation updates and corrections to calculations. An e-mail will be sent to a number of IEP reflectors when any such modifications are made to improve communication to Dayflow users.

MEETING REVIEWS

CALFED Science Program Expert Review Panel: Hydrodynamics and Salinity Response to Levee Breaches in the Suisun Marsh

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Introduction

The CALFED Ecosystem Restoration Program Plan proposes to restore tidal action to 5,000 to 7,000 acres in Suisun Bay and Marsh. While restoring tidally influenced habitat is considered ecologically beneficial, the effects on salinity of such actions had not previously been widely considered.

Recent modeling completed by the Department of Water Resources (DWR) suggests salinities could be altered considerably by restoring tidal influence to large tracts of land in the Suisun Marsh (Marsh) or Sacramento–San Joaquin Delta (Delta). These provocative results raised many questions regarding the modeling itself and the implications of the results. First, are the salinity results realistic? And, if so, could situations be properly modeled and implemented that benefited both the ecology and water quality of the estuary? What design issues for breaching levees for restoration are important to water quality? That is, how important is the “how big,” “how,” and “where” of restoration? And finally, can the results be tested in the field?

To address the above questions, CALFED, in cooperation with DWR and the U.S. Geological Survey (USGS), hosted a workshop on “Hydrodynamics and Salinity Response to Levee Breaches in the Suisun Marsh” on June 27–28, 2001 for the CALFED Science Program’s expert review panel. The purposes of the workshop were to (1) present relevant technical issues to the panel members, (2) obtain public input to the review process, and (3) obtain direction from panel members on future research and modeling needs. The panel is considering public input, modeling, and data analysis, and a report is expected sometime in 2002.

Background

The CALFED Suisun Marsh Levee Investigation Team. Extensive levee breaching and overtopping occurred in Suisun Marsh during winter storms in February 1998, prompting DWR to conduct modeling studies assessing the effects on water quality in the Marsh and Delta. Results of the modeling indicated that levee breaches in the Marsh tend to increase salinity in the region of the breach but may decrease salinity far from the breach when the breach opening is kept relatively small. However, if breach openings were left unrepaired and allowed to widen, water quality tends to decrease across the entire system.

These studies showed the importance of the Suisun Marsh to Delta water quality and prompted CALFED to participate in additional investigations into this relationship. The CALFED Suisun Marsh Levee Investigation Team (SMLIT) was established to determine if Marsh levees should be included in the CALFED program and whether there are opportunities for ecosystem restoration in the Marsh and water quality improvements in the Marsh and Delta. Studies conducted by the SMLIT showed that levee breaches in Suisun Marsh can have important effects on the currents, tidal prism, and salinity regime of San Francisco Estuary. Conversely, engineered levee breaches, in concert with innovative levee designs, may reduce Delta salinity while advancing ecosystem restoration goals and protecting existing waterfowl habitat.

The SMLIT has completed its final report, which will serve as a technical appendix to the Suisun Marsh Charter Group’s Implementation Plan. In the report, the SMLIT concluded that protection of Suisun Marsh levees is critical for Delta salinity control and that additional opportunities exist for improving water quality and enhancing habitat.

The Suisun Marsh Charter Implementation Team. Concurrent with CALFED’s investigations of the Marsh, interested agencies were coming together to develop a plan for implementing CALFED goals, water project mitigation responsibilities, and endangered species conservation for the Marsh. In the past, state, local, federal, and landowner agencies have had conflicting ideas of what the Marsh should look like in the future. The Charter Group was formed to address the interests of all the parties and devise a unified direction and plan for the Marsh. The Charter

Group is creating an Implementation Plan to improve the existing and restored habitats of the Marsh. Rigorously reviewed modeling will be beneficial in the future to studies and projects falling under the Charter Group's plan.

The CALFED Science Program and Expert Panel

The CALFED Science Program serves as a forum for review of scientific issues pertinent to CALFED studies. The Science Program strives to establish world-class science through unbiased, relevant, authoritative, integrated, and communicated science. The Science Program began in 1999 with Dr. Samuel N. Luoma named Lead Scientist. He stated at the workshop that CALFED science should be "unquestionably of the highest quality and unquestionably balanced" so that policy-makers can make informed decisions.

The SMLIT requested that the Science Program assemble and support an expert panel to review their modeling methods and conclusions. In selecting the members of the panel it was acknowledged that they must be distinguished in their field and highly knowledgeable of estuarine hydrodynamics modeling and/or processes. The Science Program also felt it was important to bring in an outside expert who does not currently work in the Bay-Delta Estuary and could perhaps lend a new perspective to the panel. Brief biographies of the panel members are provided below.

Jon Burau, U.S. Geological Survey. Jon Burau is a project chief with the USGS with 15 years experience studying the hydrodynamics of North Bay and the Delta. Jon's research the last few years has focused on field investigations of estuarine physics with an emphasis on tidal and residual circulation, and the transport and fate of salinity, suspended sediment, and non-motile organisms. Examples of specific studies include the "Entrapment Zone" studies of the mid-1990s, dye and fish migration studies in the south Delta, investigations of shallow water habitats, such as Honker and Grizzly bays and Sherman Lake, and more recently, salmon migration studies at the Delta Cross Channel and at the head of Old River.

Richard Denton, Contra Costa Water District. Richard Denton is the Water Resources Manager for CCWD's Water Resources Division. Richard has participated in Bay-Delta workgroups, hearings and other proceedings since 1989. He has had extensive experience modeling and analyzing Central Valley operations and flow and salinity regimes in the Delta. In 1995, Dr. Denton received the first annual Hugo B. Fischer Award from the California Bay-Delta Modeling Forum in recognition of his development and innovative application of a salinity-outflow model for the Delta.

Rocky Geyer, Woods Hole Oceanographic Institute. W. Rockwell Geyer is a Senior Scientist at WHOI specializing in estuarine and coastal transport processes, with particular interest in stratified flow dynamics and sediment transport. He has worked in many different estuaries and coastal environments, including the Amazon, the Pacific Northwest, New England, the Hudson River, the Eel River, and the western Gulf of Maine. His research includes a blend of observational process-studies and numerical modeling, directed both at basic research questions and applied problems of societal concern, such as harmful algal blooms and contaminant transport.

Mark Stacey, UC Berkeley. Mark Stacey is an Assistant Professor in Environmental Engineering at the University of California, Berkeley, specializing in Environmental Fluid Mechanics. His research focuses on the dynamics of stratified environments, particularly tidally-driven estuaries, with much of his work examining San Francisco Bay. Dr. Stacey's recent Ph.D. dissertation was on turbulence processes in Suisun Bay.

The CALFED Science Panel Review Process

The Levee Breach Panel Review Process included several sessions during summer and early fall of 2001. The panel received modeling results and mechanisms analyses several months before the workshops. The June 27–28 workshop was the kick-off session to present the modeling results and relevant field data to the panel and the general public. The first day of the workshop focused on informing and obtaining input from the public. The second day was a smaller session to discuss the details of the modeling and to assign and prioritize future modeling requirements based partly on the public input received. E-mail facilitates regular group discussion among the panel members and modelers. Subsequent meetings and workshops will further scope the model attributes needed to appropriately simulate levee breach scenarios.

The Workshop

Larry Smith, USGS, and Chris Enright, DWR, organized and co-chaired the workshop. The workshop was opened by Curt Schmutte, DWR, and Sam Luoma. Curt emphasized the need for collaboration and coordination in solution design between the four primary CALFED programs: Ecosystem Restoration, Water Supply Reliability, Flood Control, and Water Quality. He also stated that we are evaluating the potential to do what otherwise would take a "billion-dollar reservoir to do in terms of Delta outflow, water quality, and water supply reliability." He further acknowledged the importance of peer review and stakeholder acceptance of the modeling so that it can be effectively used for problem solving and design.

Sam Luoma placed the importance of accurate hydrodynamics and water quality modeling in the broader perspective of CALFED. He stated that the "Suisun Marsh and central Delta are crucial parts for all four of these [CALFED] goals" and the initial modeling runs under evaluation show that these locations are "where some of the most important interconnections and complexities can occur." He emphasized the purpose of the workshop as a combination of peer-review and open communication. It should also assist in determining what should be done in the future and how we can better communicate the findings to others. Although the studies under consideration have occurred over the past two years, it is important to recognize that this is the beginning of a process, not the end, since a successful review will spawn new ideas for study.

To focus the workshop, Larry Smith posed three specific questions to the panel and workshop attendees for consideration:

1. What evidence exists that levee breaches in the Suisun Bay and Marsh area influence Delta salinities?

2. What are the candidate physical mechanisms that might explain these influences?

3. What science is necessary to select or reject any of these candidate mechanisms?

Summary of Levee Breach Modeling Results

Two presentations were made on levee breach modeling to assist in answering the above questions. Chris Enright presented one-dimensional model results from DWR's Delta Simulation Model 1 (DSM1) and DSM2. John DeGeorge, Resource Management Associates (RMA), presented two-dimensional modeling results from the RMA model. All three models, though functionally quite different, resulted in similar salinity trends. Each of the models showed that breaches in the Suisun Bay and Marsh can significantly affect Delta salinities.

After discussing results, both presenters focused on two competing mechanisms creating the salinity trends exhibited by the models. These two mechanisms are tidal asymmetry and tidal range reduction. While tidal asymmetry caused by a breach with a small opening tends to increase salinity mixing, tidal range reduction due to opening a new area to tidal flow tends to decrease salinity mixing.

Relevant Hydrodynamic Analyses

Jon Burau and Dr. Jessica Lacy, USGS, highlighted results of field work in the context of the breach questions. Jon presented data showing the baroclinic flow patterns in the Suisun Bay and Marsh. While baroclinicity is strong in the San Pablo Bay, it is not particularly strong in Suisun Bay. However, if breaches in the marsh are affecting tidal energy, they could be affecting the baroclinicity. Changes to tidal energy and the resulting effect on salinity supply could significantly affect the real-world effects of breaches. Jon also presented data supporting the large flow exchanges that are possible through shallow water habitat areas such as Sherman Lake, and evidence of gravitational circulation in Montezuma Slough.

Jessica Lacy's presentation was titled "How do circulation and transport in shallows and channels differ?" Her field study focused on the complicated circulation patterns of Honker Bay and Suisun Cutoff. She concludes that Honker Bay is not well-mixed laterally. Because of Honker Bay's semi-enclosed configuration, it's contribution to dispersion is greater than for an open shoal. This field data could imply that at least a two-dimensional model is needed to capture this longitudinal variation.

Group and Panel Discussion

After the presentations, workshop attendees and panel members were given the opportunity to comment. Below are key questions from the audience:

- What are the biological and ecological implications of the model results?

- What are the effects of geometry changes over time, such as sedimentation or breach size?
- Are the models applicable to other areas (breaches in San Pablo Bay or the Delta)?
- What are the cumulative effects of numerous projects in the San Francisco Bay estuary?

The panel emphasized the need to use existing field data for additional validation and calibration through historical comparisons. Several specific suggestions were made for additional hydrodynamics analysis to elucidate the potential mechanisms of mixing in the system.

Actions to further improve the modeling capabilities were drafted in a phased, three-year plan. These actions include calibration and validation activities, mechanistic investigations, and data collection efforts. The panel encouraged use of a three-dimensional model to compare to the modeling done so far.

Conclusions

The focus questions initially posed to the panel and workshop attendees were answered in brief:

1. Modeling and field evidence show that levee breaches in the Suisun Bay and Marsh do affect Delta salinities.

2. Candidate physical mechanisms could include tidal asymmetry, tidal range reduction, baroclinicity effects, and tidal energy changes.

3. Additional science would assist in further identifying key candidate mechanisms for salinity mixing. Mechanisms should be examined using classical tidal hydrodynamics analysis techniques in concert with comparisons to field data sets.

As evidence to the success of the workshop in spawning new ideas, many new questions were raised over the course of the two-day review. The CALFED Science Program review provides an invaluable process that furthers the hydrodynamics modeling of the estuary. Ultimately, this process should provide clarify the use of various models to assist in addressing complex, ecosystem-scale project design questions to managers and planners.

IEP Resident Fish Project Work Team Hosts Meeting on Green Sturgeon

Lenny Grimaldo and Steve Zeug (DWR)
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The green sturgeon (*Acipenser medirostris*) is an anadromous fish that spends most of its life cycle in estuarine and marine habitats. Along the Pacific coast of North America, green sturgeon have been found as far south as Mexico and in the north up to Southeast Alaska. Green sturgeon are relatively more common in the San Francisco Estuary, Klamath River Basin, and the Columbia River. Green sturgeon migrate during the spring to large rivers for spawning. Young-of-the-year fish may rear up to two years in the river before migrating back to the estuary or ocean. Reproductive maturity is reached between 12 and 15 years of age and individual spawning events may occur once every 4 to 11 years.

On August 30, the IEP Resident Fish Project Work Team hosted a thematic meeting on green sturgeon. The meeting was prompted by the recent petition to list green sturgeon and the recognition that very little is known about this prehistoric fish that inhabits the Central Valley watershed and San Francisco Bay. The purposes of the meeting were to discuss green sturgeon life history and identify the data gaps most relevant to the management of the species. Two major products were identified for next year: (1) A proposed white paper on green sturgeon led by Ray Schaffter (DFG) and other IEP personnel and (2) an IEP-sponsored e-mail listserve (sturgeon@water.ca.gov) that can be used to communicate sturgeon information among interested stakeholders. The remainder of this article is devoted to a summary of the information presented at the meeting on green sturgeon.

Petition to List Green Sturgeon: Regulatory Steps Ahead

Rick Sitts (Metropolitan Water District)

Rick presented the nuts and bolts behind the petition to the National Marine Fisheries Service (NMFS) to list the green sturgeon and the potential regulatory obstacles ahead if the animal is listed. The listing process can involve two phases. The first phase includes a 90-day finding period and perhaps a 9-month status review. During the finding period, NMFS must ascertain under the “reasonable person test” that adequate and reliable information is available to proceed to the next phase. If so, then NMFS conducts the status review, during which interested parties can respond to the scientific rationale cited in the petition as the cause for population decline and present other information. At the conclusion of the status review, NMFS either proposes a new regulation or deems the action unwarranted. Five factors were listed as reasons for a green sturgeon population decline:

- Reduced habitat and range, including effects of water development.
- Overfishing by commercial fisheries and high incidental catch.
- Disease or predation.
- Inadequate regulatory mechanisms.
- Entrainment and toxins.

Rick was generally concerned with the lack of evidence that the historical home ranges of green sturgeon have declined substantially over the years. He was also concerned with the view that population levels have steadily decreased given catches of green sturgeon in the San Francisco Bay have always been very low and highly variable. Additional concerns presented were the general poor understanding of green sturgeon ecology and population dynamics. Rick noted that listing may hamper research (due to take limits) and that CALFED's Multi-Species Conservation Strategy has over 15 actions for green sturgeon restoration, including increased or improved habitat, reduced fishing, and pulse flows.

Development of Molecular Markers to Study the Population Structure of Green Sturgeon
Josh Israel (UC Davis)

Josh Israel's study objectives are to develop interspecific molecular markers to differentiate juvenile green and white sturgeon and to develop intraspecific markers to look at population structure. Samples of green sturgeon from the Columbia River estuary and the Klamath River were analyzed using nuclear molecular markers to determine if all fish were of Klamath River origin or if Columbia estuary fish were from multiple populations. Josh found the following:

- Juvenile white and green sturgeon can be differentiated using restriction fragment length polymorphism analysis (RFLP).
- Unique alleles found in Columbia River samples indicate the presence of a genetically distinct population from that on the Klamath River.
- Temporal sample coverage from more locations is needed in future work to determine the number of genetically distinct populations.

Green Sturgeon Reproduction
Serge Doroshov (UC Davis)

Dr. Serge Doroshov has been conducting several years of research on green sturgeon reproduction in the Klamath River, California. Most of the fish are collected as incidental catch of the Native American salmon fishery. He has looked at several components of green sturgeon reproduction including fecundity, egg morphology, and larval growth and behavior. Much of the information on green sturgeon is compared here to white sturgeon, which has been cultured and studied more thoroughly.

- Male and female size and age structure of mature broodstock is similar to other sturgeons.
- Green sturgeon fecundity has a linear relationship with female size and the average fecundity is 40% less than in white sturgeon of similar size. However, lower fecundity is compensated for by larger egg size, which improves larval survival.
- Green sturgeon eggs are less adhesive then white sturgeon eggs.
- Embryonic development and growth rates are similar for both species; however, green sturgeon young are two times as large at first feeding due to larger egg size.
- Green sturgeon larvae show no pelagic behavior after hatching. They are demersal and show a nocturnal clumping behavior six days after hatching.

Population Trends of Green Sturgeon in the San Francisco Estuary
Dave Kohlhorst (DFG)

Dave Kohlhorst presented information on green sturgeon population trends as detected using screw trap and trammel net monitoring. Dave described the difficulty of developing an abundance index for green sturgeon given the low numbers collected annually. Since sufficient numbers of white sturgeon are collected annually (using

Peterson mark-recapture methods) to estimate population size, the ratio of white sturgeon to green sturgeon is used to estimate green sturgeon population size. Dave noted mostly juveniles were collected in San Pablo Bay. The mean size collected was 100 mm fork length. This indicates that these fish are immature and not "run backs" from spawning earlier in the year. Population trends here are highly variable and low numbers collected may confound accurate abundance estimates.

Green Sturgeon Physiology
Joe Cech and Peter Allen (UC Davis)

Dr. Joe Cech presented physiological studies conducted by one of his former graduate students, Ryan Mayfield (currently of DFG), and briefed the audience on treadmill work his lab will begin over the next couple of years. Peter Allen is currently investigating green sturgeon salinity tolerances through juvenile developmental stages. Joe also presented preliminary data on green sturgeon growth responses to water temperature. He also mentioned that Scott Lankford from his lab would be examining the role of cortisol in green sturgeon stress response (chronic and acute). So far, his research team has found the following:

- Increases in temperature and ration size generally increased juvenile growth rates.
- Fish fed to 100% satiation at 11 °C had a lower food conversion efficiency then fish fed to 50% satiation at higher temperatures (19 and 24 °C).
- Food conversion efficiency was greater with reduced (50% satiation) rations and warmer temperatures (19 and 24 °C) than full rations (100% satiation) and cooler temperatures (11 °C).
- Oxygen consumption rates did not differ between 11 and 19 °C; however, there was a substantial increase between 19 and 24 °C.
- Swimming velocity did not significantly change with increasing water temperature.
- Growth was fastest at 19 °C and decreased at 24 °C.
- Juvenile green sturgeon acclimated to 24 °C were found associated with warmer water temperatures than those acclimated to cooler water temperatures.

Green Sturgeon Fisheries in the Eastern Pacific: Are Harvest Rates Sustainable?
Tom Rien (Oregon Department of Fish and Wildlife)

Tom presented some interesting observations on green sturgeon in Oregon estuaries. Perhaps most interesting was that they have yet to find a food item in green sturgeon stomachs from the Columbia River, although more than 50 fish have been examined. The fish are not in the Columbia River estuary for spawning or feeding. Speculations about why the fish are in the estuary include thermal refuge and safe harbor from ocean predators. Tom noted there is no commercial fishery that targets green sturgeon in Oregon or Washington. Commercial harvest of green sturgeon comes from incidental catch among white sturgeon and salmon fisheries in Oregon and Washington estuaries, primarily in August.

- More information is needed on abundance, survival, population dynamics, and habitat use.
- Harvest is mostly in the coastal estuaries and bays of Oregon and Washington. Only 10% of the total harvest comes from the Klamath River.
- Biologists from the Yurok and Hoopa tribes, the U.S. Fish and Wildlife Service, UC Davis, and the states of Washington, Oregon, and California met last year in Witchepec, California. All agreed to openly share information, and fisheries managers agreed that while we did not believe the population was in decline, conservative fishery management is appropriate and that expansion of fisheries is not recommended.
- Oregon and Washington fisheries managers will review current regulations and consider changes that will continue to protect green sturgeon.
- There is currently low fishing effort in August, when green sturgeon catches are typically highest.
- Fisheries data from the Columbia River show harvest numbers are reduced and average size of green sturgeon has increased. One interpretation is that the green sturgeon population is stable and the harvest declines are simply the result of declining effort. However, if juvenile recruitment has dramatically declined, these fish will likely need additional protection.

Green Sturgeon Harvest in the Klamath River Basin
Dave Hillemeier (Yurok Tribal Fisheries)

The Yurok Tribe has fished for green sturgeon on the Klamath for thousands of years. For this reason the tribe is very interested in the continued health of green sturgeon populations on the Klamath River Basin. Some of the work that has been done includes monitoring of the tribal fishery and cooperating with various agencies such as UC Davis and Humboldt State University to conduct research on green sturgeon. Attempts are underway to acquire funding to conduct tracking studies, as well as studies to characterize habitat used by adult and juvenile green sturgeon.

- Anecdotal information indicates the upper range for green sturgeon in most water years to be Ishi Pishi Falls and the Salmon River in the Klamath Basin and Grays Falls in the Trinity Basin.
- Mean Yurok harvest from 1983 to the present is 264 fish per year. Mean coastwide harvest is 4,216 during the same period.
- Fishing effort and catch per unit effort in the Yurok fishery has been variable among years.
- Length data collected from the Yurok Fishery since 1980 indicate no decline in size.
- Inaccuracies contained in the recent petition regarding the Yurok Fishery were clarified.

Use of Radio Telemetry to Describe Movements of Green Sturgeon in the Rogue River, Oregon
Dan Erickson (Wildlife Conservation Society)

Dan Erickson tracked the movements of 19 green sturgeon in the Rogue River were followed using radio telemetry. Most tagged fish spent more than six months in fresh water up to river kilometer 39. Green sturgeon were found to stay in specific holding areas for months at a time. All tagged individuals emigrated from the system during the fall and winter, when water temperatures dropped below 10 °C and when flows increased. This species is extremely vulnerable to habitat alterations and overfishing because it spawns in only a few North American rivers and individuals reside within extremely small areas for extended periods of time.

- Fish entered the river in March (possibly February).
- Some individuals were ripe, indicating that fish are spawning in the Rogue River.
- Holding sites were typically deep (> 5 m) low-gradient reaches or off-channel coves.
- River residence time may be more than six months.
- Flow and temperature correlated with emigration.
- More information is needed on spawning habitat, feeding habits, and oceanic distribution.

Green Sturgeon Salvage Dynamics
Lenny Grimaldo (DWR)

Lenny presented data on green sturgeon salvage at the State Water Project export facilities in the South Delta. He indicated that taxonomic resolution may be lacking for fish identified as green sturgeon in the early years of salvage operations, however, his data do give an idea about the relative numbers of green sturgeon salvaged.

- 126 fish identified as green sturgeon have been salvaged since 1973, compared to approximately 500 white sturgeon.
- The number of fish salvaged per year is highly variable and higher numbers may be correlated with high water years.

A Proposal to Investigate Green Sturgeon Movements in San Francisco Bay
Carlos Crocker and Veronica Wunderlich (SFSU Romberg Tiburon Center)

This study proposes to use sonic tags to describe movements and habitat use of green sturgeon in San Francisco and San Pablo bays. A preliminary study has already begun. On September 17 a sonic tag was surgically implanted into a green sturgeon. The fish was released on September 21 and was tracked continually until September 25. Volunteers from UC Davis and San Francisco State are worked in 12-hour shifts to continually track the sturgeon.

- Veronica Wunderlich is preparing a proposal to study the effect of temperature and dissolved oxygen on green sturgeon survival.
- Carlos Crocker is currently seeking a facility and funding for long-term tracking and monitoring of

both green and white sturgeon habitat use in San Francisco and San Pablo bays.

Summary

The consensus among the group was that much was learned during the day, and the meeting was fruitful for developing working hypotheses to augment our current knowledge about green sturgeon life history. Life history information needed is related to green sturgeon feeding habitats in the various estuaries, migratory movements along the coast, spawning triggers, and estuarine rearing or residence times. Many also noted that the preliminary evidence suggests green sturgeon behave differently from white sturgeon, although abundance estimates seem to correlate during above normal water years. Some relevant management issues discussed were the potential for several green sturgeon environmentally significant units to be present along the Pacific; biases among gear methods used to estimate green sturgeon abundance; and the potential for take limits to hamper future research if green sturgeon are listed. Also mentioned was the importance of incorporating green sturgeon swimming velocity information in screening efficiency standards with other listed species. The meeting concluded with many participants discussing potential collaboration efforts with field and lab studies. The group agreed to meet in two years to discuss progress on current research investigations.

CALFED's Salmonid and Delta Smelt Environmental Water Account Workshops

Wim Kimmerer (SFSU Romberg Tiburon Center), kimmerer@sfsu.edu; and Randy Brown (DWR, retired)

We are working as advisors to CALFED's Lead Scientist, Sam Luoma, on the Environmental Water Account (EWA). As part of that activity we were involved in planning, conducting, and reporting on two recent workshops sponsored by the CALFED Science Program. Although these workshops had somewhat different purposes, both were aimed at improving communication and consolidating recent gains in knowledge to continue to improve the estuarine ecosystem and, in particular, species of concern. The workshops continued an effort begun by the CALFED Science Program with the splittail workshop in January 2001. The splittail and delta smelt workshops also were linked to the respective CALFED white papers.

Three objectives were active in the delta smelt and salmonid workshops. The first was to assess the current state of knowledge about the ecology of these fish. The second was to evaluate the potential effect of EWA actions on the fish. The third was to help prepare for an EWA scientific review meeting held on October 22–24, 2001.

Specifically excluded from the agenda of both workshops was any discussion of whether or not the EWA was "successful"—that discussion will occur after three additional years of evaluating EWA benefits. Instead, the presenters and attendees, especially of the delta smelt workshop, focused on scientific issues. A summary of both workshops is available on-line at http://www.calfed.water.ca.gov (click on "Science"). Here we summarize the content of both workshops and present our views on their key outcomes and values.

The Environmental Water Account

The Environmental Water Account (EWA), part of CALFED's Water Management Program, is designed to balance two sometimes conflicting objectives: (1) to protect endangered fish and (2) to avoid interruptions of water deliveries by the state and federal export facilities caused by crises developing from the first objective. The EWA is built on the premise that water can be obtained and banked until needed for actions to protect fish or aquatic ecosystems. Water is acquired by several methods, such as purchasing existing water rights and relaxing Delta water quality standards (for example, the Export:Inflow ratio) when project-pumping capacity is available. The water may be stored as groundwater or in reservoirs upstream or downstream of the Delta. The amount of water available each year depends in part on hydrology, but the goal is to have an average of at least 200,000 acre-feet available each year.

In the first year, the EWA operated mostly in the Sacramento–San Joaquin Delta in conjunction with existing regulatory actions (State Water Board water quality control plans and water rights permits) and CALFED's Environmental Restoration Program. Since 2001 was the first year of a proposed initial four-year evaluation of the EWA, actions taken this year should be viewed in that context. Information obtained in 2001 will be used to improve the process in subsequent years.

The Salmonid Workshop

Most of the EWA actions in 2001 were taken to protect young salmon migrating through the Delta—in particular to protect juvenile winter run. We should point out that, in many cases, actions to protect salmon also protect delta smelt and other species. Since there were numerous, contentious issues relating to those actions, it was appropriate to focus the workshop agenda on the decision process, models, and calculations that were used to justify the actions taken for salmon and to interpret the degree of improvement of the populations.

There were principal questions posed for the use of the EWA to protect migrating salmon smolts:

1. How many spawners are in the population?
2. What is the relationship between spawner abundance and number of emigrating smolts?
3. What is the relationship between the rate of water diversion and take of salmon smolts at the export facilities?
4. What fraction of the emigrating smolts is taken and by how much can this be reduced by EWA actions?
5. What are the population consequences of take, including any EWA-related reduction?

Calculating Take at the Export Facilities. Calculating the number of juvenile winter run entering the Delta and allowable take at the export facilities is based on estimating the number of female spawners, their fecundity and egg to smolt survival. Take (the number of salmon killed) at the export facilities is calculated from numbers salvaged by using estimates of mortality in front of the screens, through-screen losses, handling and trucking losses. NMFS sets the maximum allowable take for winter-run salmon at 2% of the estimated number of emigrants, assuming that about half of the fish classified as winter-run based on size are actually genetically winter run, and that a 1% take would not jeopardize this endangered race.

Since the late 1960s winter run spawning estimates have been based on the number of winter-run observed passing through the fish ladders at the Red Bluff Diversion Dam (RBDD). In the past several years, the dam gates have been raised during most of the period of adult upstream movement, and most migrating adults do not use the fish ladders. Biologists have used past records to determine that about 15% of the adults moved upstream after May 15, the date when the gates are now lowered. The biologists now count the small proportion of fish using the fish ladders and extrapolate that number for the final estimate, assuming that the 15% value holds in every year.

At the workshop Rob Titus (DFG) reported on estimates developed from carcass surveys beginning in 1996. Using Peterson mark-recovery procedures, DFG estimated that the spawning run for 2000 might have exceeded 6,600 adult winter run, more than four times the estimate based on RBDD counts. In addition, there were major differences in sex ratios between the two estimates, with the carcass counts showing a higher percentage of females than the 1:1 female-to-male ratio assumed by NMFS in calculating the number of juveniles entering the Delta. The increased number of spawners and the higher percentage of females would lead to higher estimates of egg production than would occur using the NMFS estimating procedures.

On the other hand, survival estimates from egg to fry and fry to smolt are not well known and based on poorly documented studies. At the workshop there was some discussion of updating the historical values using more recent data, but no data were presented. Thus, the method used to estimate the number of emigrating smolts may be outdated. Steve Lindley (NMFS) discussed a proposed state-space model to be developed that would be used to estimate these key parameters using all of the available data.

Take at the pumps would be a relatively straightforward calculation from salvage were it not for estimated predation losses in the Clifton Court Forebay. An estimate of 75% loss has been used based on mark-recapture experiments. However, the experimentally-estimated losses are widely scattered, and calculated take is extremely sensitive to the predation rate used. For example, using a 75% loss value, take would be four times salvage, whereas for 90% loss, take would be ten times salvage.

The reduction in take due to EWA actions was calculated as the product of the reduction in pumping times the take per volume during the time the pumping was reduced. With this calculation Sheila Greene (DWR) estimated that EWA actions saved about 6,000 juvenile winter run. Although there was some deliberation about what happens to fish not taken (Are flow patterns in the Delta altered enough to make these fish more vulnerable later on?), no one could offer a definitive response.

Several alternative models were presented that estimated the effect of pumping and reductions in pumping on the fraction of emigrating smolts lost. Pat Brandes (USFWS) presented a model showing an effect of export flow on the mortality of smolts migrating down Georgiana Slough and calculated estimates of losses using the model. B.J. Miller (consultant to San Luis and Delta-Mendota Water Authority) presented an alternative approach using a more sophisticated statistical model of the smolt mark-recapture data developed by Ken Newman (University of Idaho, consultant to IEP) showing that the fraction of salmon "saved" was quite small.

Population Level Effects. Population-level effects were discussed at the workshop but little progress was made. Obviously this is the ultimate target at which analyses should be aimed, but we are just beginning to string the bow.

The workshop presentations and discussion indicated that the various agencies were able to work together to develop and execute a complex plan to allocate EWA water and to respond quickly to changes. This cooperation continues as the agencies prepare a major report for review by the EWA Review Panel, stakeholders, and CALFED. From a biological perspective, it was clear to participants that substantial gaps in our knowledge make it difficult to evaluate the EWA from a population perspective.

The Delta Smelt Workshop

The delta smelt workshop was focused less on the EWA and more on basic delta smelt biology. This workshop, organized by Zach Hymanson (DWR), brought together nearly all scientists currently working on this enigmatic fish.

Researchers at UC Davis working on culturing delta smelt described aspects of their basic biology related to water temperature and feeding. The influence of temperature was clear from these results. Spawning occurred at a temperature range of 7 to 15 °C. Growth of larvae and juveniles was highest at 20 °C, but survival of larvae was highest at 17 °C. Unfortunately, we do not have the water temperature monitoring data for the Delta-Suisun Bay complex that we need to evaluate water temperature effects on delta smelt. The presenters identified water temperature data as a high-priority need for understanding delta smelt (and other fish). Feeding experiments also showed that early delta smelt larvae need turbid water to begin feeding. The culture studies not only yield valuable information on delta smelt biology but, for the first time, provided about 10,000 juvenile delta smelt to researchers.

Sampling Issues and Salvage at the Export Facilities. There was considerable discussion about sampling issues. Various sampling programs give somewhat conflicting pictures about delta smelt abundance patterns, although this phenomenon is typical for fish collected with different gears. The salvage facilities are relatively inefficient at screening early juvenile smelt, and many smelt are entrained in the export pumps. Actual fish screen efficiencies for delta smelt and the influence of predators in front of the screens are unknown. In addition, seasonal and diurnal salvage at the state and federal export facilities differs markedly. Part of the difference is due to operational patterns and presence of Clifton Court Forebay at the SWP intake, while other parts are unexplained.

The low sampling efficiency of the salvage facilities for small delta smelt may result in some anomalous salvage patterns. Matt Nobriga (DWR), Lenny Grimaldo (DWR), and Zach Hymanson presented a theory by which the reductions in exports for the Vernalis Adaptive Management Program (VAMP) led to better larval survival. Larvae are not sampled well at the salvage facilities. The juveniles, now greater than 20 mm, can be salvaged and reported as take. In essence, the models suggests VAMP may have improved delta smelt rearing conditions in the south Delta and more juveniles of salvageable size are now reaching the facilities. This may explain why salvage levels have been high in most recent years. They also hypothesized that delta smelt may rear in Clifton Court Forebay (resulting in high salvage) and offered a plan to test this hypothesis.

Bill Bennett showed evidence of a density-dependent relationship between the summer townet index and the fall midwater trawl index. His results generated some discussion, and Bill suggested that the townet index may be biased because of annual differences in temperature-dependent spawning time that result in the fish reaching different sizes at the time of the townet survey. However, the same is true for striped bass, which initiated the method of calculating the delta smelt index using the same two surveys each year that were used to calculate the striped bass index. Unfortunately, discussion of this issue did not produce data (or even a promise of data) to refute the finding of density dependence. Density dependence is a key issue for assessing the population biology of any species, particularly one under threat of extinction, and should be investigated further.

Contributions of 2-Year-Old Fish. The hypothesis that 2-year-old fish contribute more to year-class recruitment than 1-year-old fish is based on analyses of monitoring data that show significant autocorrelation at lag 2 years. Fish aged 2 years appear to make up 3% to 8% of the population, but are presumably more fecund than 1-year-old fish, thereby contributing more to recruitment in some years. More data are needed to demonstrate that 2-year old fish contribute out of proportion to their relative abundance.

Delta Smelt Movements. Delta smelt movements are of great interest because of the general goal of getting them as far from the pumps as possible. Suggestions still surface about the possibility of "pushing" the delta smelt seaward with freshwater flow Available data suggest this can happen at high flows; however, delta smelt often take up residence or move unpredictably. It was suggested that water temperature is an important mechanism affecting fish movement, which is supported by the UC Davis laboratory data discussed earlier, but so far field data do not convincingly support this mechanism.

Relationship between X2 and Abundance. Delta smelt abundance and X2 show a weak relationship, which has always seemed odd, especially since longfin smelt abundance demonstrates the tightest relationship to X2 of any species in the estuary. Bruce Herbold previously introduced the idea of "X2 days," the number of days that X2 is in Suisun Bay, as an independent variable explaining at least some of the variance in delta smelt abundance. Bill Bennett showed a relationship between the residuals from the summer-fall, stock-recruit curve and X2 days. However, this relationship remains a paradox that cries out for research attention.

The effect of EWA actions in spring 2001 on delta smelt was discussed but not emphasized. Although few of the export reductions were expected to help delta smelt, their salvage did not reach red light levels as in 1999 and 2000. This could indicate that EWA actions were effective, but it is equally likely that abundance was low or it was merely a coincidence.

A panel discussion of research needs did not result in much dialog. Each speaker raised different issues and there was little debate. Some identified research needs included water temperature and salinity effects, habitat use, and application of methods including histopathology and modeling. Panel members were asked to invent experiments that could be performed under the EWA program, but nobody did so. Zach Hymanson did suggest that smelt biologists develop a prioritized research plan, perhaps to include a long-term study of flows, pumping, and barriers analogous to the Vernalis Adaptive Management Plan.

Conclusions

We found both workshops to be successful from the standpoint of transfer of information. Both could have benefited by more time for discussion, but the organizers wanted to keep them to day-long events. The results of the salmonid workshop were presented to the EWA Review Panel. Unfortunately we did not complete the delta smelt workshop summary in time for their scheduled review, so some presenters provided their data, conceptual models, and indicators directly to panel members at the October meeting.

Lastly, we present a few general conclusions:

1. We have learned from these and many other examples that a well-structured workshop is a valuable method for helping people to think conceptually, encouraging discussion and interaction, and even for resolving issues. However, we believe workshops may be more valuable when the emphasis is on products rather than presentations. The need to produce something that may encourage actual collaboration and more rapid progress toward workshop goals.

2. Data collected by IEP needs to be converted to information and submitted as articles for peer-reviewed publication. The publication process, including peer-review, provides an excellent vehicle for making hypotheses, conceptual models and conclusions available to other scientists and to managers.

3. All three workshops (on splittail, delta smelt and salmonids) provided general ideas about research and monitoring needs. Biologists working on these species must follow through with the ideas discussed and develop both short and long-term research plans.

Development of these plans could benefit from participation by non-IEP scientists.

4. The white papers commissioned by CALFED in 2000 were to be used to guide restoration and research. The delta smelt white paper should be updated with the material presented at the workshop and circulated for constructive review. In particular, the paper should clearly identify the areas of uncertainty or controversy. This white paper could then form the basis for a comprehensive research plan, as mentioned earlier. Previous efforts to develop such a plan have fallen short, and a plan is needed if we are to make rapid and consistent progress toward resolving some of the thorny issues concerning the biology and protection of delta smelt.

Applications of Stable Isotopes Research in Understanding Complex Ecological Processes in the San Francisco Estuary

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The use of natural abundance isotopes or "stable isotopes" by geochemists, ecologists, and contaminant biologists working in both aquatic and terrestrial environments has grown over the past 15 years. In aquatic ecology, stable isotopes have been used to answer specific questions about mechanisms at various levels from individual organisms to communities and ultimately whole ecosystems. They help us to identify patterns and mechanisms in nature that previously were not easily measured or quantified.

Stable isotopes are a measure of the ratio of the heavy and light isotopes in a sample compared to a standard (Lajtha and Michener 1994). For example, for carbon, the heavy isotope is ^{13}C, the light isotope is ^{12}C, and the standard is the marine limestone fossil Pee Dee belemnite. Although both isotopes react the same chemically, a variety of chemical and physical processes result in isotopic fractionation, which results in the enrichment (more ^{13}C relative to ^{12}C) or depletion of the heavier isotope relative to that observed in the standard material. Differences in the isotopic ratios between samples and standards are reported as δ values where,

$$\delta(\text{ppt or per mil}) = \left(\frac{\text{Ratio}_{\text{sample}}}{\text{Ratio}_{\text{standard}}} - 1\right) \times 1000$$

The processes of isotopic fractionation varies for different isotopes which in turn determine the type of information obtained. The most commonly used stable isotopes in ecology are carbon ($^{13}C/^{12}C$), nitrogen ($^{15}N/^{14}N$), sulfur ($^{34}S/^{32}S$), oxygen ($^{18}O/^{16}O$) and hydrogen ($^{2}H/^{1}H$).

The usefulness of stable isotope ratios to ecologists arises from the predictability of physical and enzymatic-based fractionation, which creates different isotopic signatures. For example, plants using the C4 photosynthetic pathway (such as *Spartina foliosa* or cord grass) tend to have more enriched $\delta^{13}C$ values than plants using the C3 pathway (like *Egeria densa*). In the case of nitrogen, we typically observe an enrichment of about 3.4‰ (range 2.5% to 5%; Cabana and Rasmussen 1994). Each trophic step from food to consumer is due to the preferential retention of ^{15}N and excretion of ^{14}N in consumers (Adams and Sterner 2000; Gannes and others 1998; Minagawa and Wada 1984). The obvious limitation to the usefulness of isotopes then, is precisely "knowing" the extent of isotopic fractionation for all reactions for physiological and ecological processes being examined. We must also meet the assumption that isotopic signatures (and variability) of all potential food sources are distinct. Furthermore, we must understand the stability of isotopic signatures in biological materials as they are transported and transformed within the environment. Stable isotope studies are not "quick and dirty" methods. They require an excellent working knowledge of the basic structure and function of the ecosystem and rarely replace tried and true ecological methods.

Given a healthy respect for the complexity of nature and by integrating information on everything from photosynthesis to fish behavior to hydrodynamics, stable isotopes studies can be extremely effective in answering challenging ecological questions. A group of scientists, who are presently using stable isotopes as part of their research in the San Francisco Estuary, held a small symposium at the USGS in Menlo Park in February 2001 to share data and ideas. The participants were at various stages of their research including design, analysis of results and manuscript preparation. This article is a summary of the symposium, designed to highlight the many ways in which isotopes are being used to answer complex ecological questions.

Using Stable Isotopes to Assess Sources of Carbon and Nitrogen to the San Francisco Estuary
Kim Bracchi and Russ Flegal (UC Santa Cruz)

By analyzing sediments in the San Francisco Estuary, we hope to relate differences in the stable isotopic signatures of organic carbon and nitrogen to natural and anthropogenic origins. It has been shown that stable isotopic abundances of $\delta^{13}C$ and $\delta^{15}N$ can be used to trace the provenance of organic matter in estuarine sediments. Our previous work shows that marine samples are enriched in $\delta^{13}C$, whereas terrestrial samples are significantly depleted in ^{13}C. Nitrogen results from 1998 were less definitive and required further study. Recent results for $\delta^{15}N$ show a slight enrichment of marine-influenced sediments relative to terrestrial-influenced sediments. Sewage has been linked to enriched $\delta^{15}N$ values in biota (Cabana and Rasumussen 1996) and may contribute to the enriched marine sediment signal. Over the past decade, there has been an increase in human-induced nutrient inputs to the San Francisco Estuary. By using nitrogen and carbon isotopes, we hope to track and quantify sewage-derived inputs to sediments. To do this, we plan to collect sewage samples from treatment plants around the bay, which will serve as end-member signals, and then calculate the relative contributions of these sources to sedimentation in the bay.

Future work on this project includes analyzing the $\delta^{15}N$ signature in dissolved nitrate and ammonia in the water column. These signatures may be useful in determining the relative contribution of different sources of nitrogen that make up sediments and particulate matter in the different parts of the estuary.

Estuarine Food Web Base Revealed by C, N Isotopes?
James E. Cloern (USGS), Anke Mueller-Solger (DWR), Elizabeth A. Canuel (Virginia Institute of Marine Sciences), and David Harris (UC Davis)

CALFED has supported a multi-institutional research program designed to answer fundamental questions about the dynamics of the food-web base in the Bay-Delta ecosystem. One fundamental question asks to identify the source(s) of organic matter that fuel biological production at the trophic level of primary consumers—organisms such as copepods, cladocerans, rotifers, clams, and suspension-feeding insect larvae and amphipods. One approach for answering this question uses stable isotopes of carbon and nitrogen in animal tissues as biomarkers to identify their potential food source(s). The approach is based on the assumption that different groups of primary producers, such as freshwater phytoplankton, terrestrial plants, and marsh plants have distinct signatures in their C and N isotope ratios. To test this assumption, we measured the C and N isotopic composition of 830 plant samples collected to represent all the potential contributors to system production in the Bay and Delta. Study design included sampling across the full matrix of habitat types and over an annual cycle to capture the full range of variability among all plant communities. This is the most comprehensive study of plant isotopic composition done in any tidal aquatic ecosystem, and we are analyzing this dataset in preparation for publication. Our results show that each plant community has large inherent variability in its isotopic composition, and that distinct isotopic signatures do not exist for any plant group in this complex ecosystem. Isotopic information alone cannot reveal the source or source mixture of the organic matter that fuels biological production in the Bay-Delta.

Along with the plant samples, we also collected a large number of zooplankton samples (mainly copepods and cladocerans) for stable nitrogen and carbon isotopic analysis. We separated the zooplankton samples into individual genera and orders. As with the plant samples, we observed a large amount of variation in isotopic signatures. Further analysis of the data will show if the zooplankton can be grouped according to food sources. These groupings could also be influenced by location, season, trophic level, and taxonomic relationships. Ultimately we hope to show trophic pathways from usable plant food to different types of zooplankton in various Delta habitats.

Delta Habitats

Bioaccumulation of Selenium in the Food Web of San Francisco Bay: Importance of Feeding Relationships and Location
Robin Stewart and Sam Luoma (USGS), Martina Doblin (Old Dominion University), and Kathy Hieb (DFG)

Selenium (Se) is an essential element that requires a delicate balance in nature. Insufficient quantities can cause deficiencies, yet too much and Se becomes a potent reproductive toxin. Selenium's complex geochemistry and variable patterns of bioaccumulation in aquatic food webs makes it a challenge for managers to predict its fate and toxicity under variable hydrologic, biogeochemical and biological regimes. Elevated selenium (Se) concentrations found in the bivalve, *Potamocorbula* *amurensis*, and benthivorous diving ducks and fish in San Francisco Bay (SFB) prompted a CALFED-supported study of the trophic transfer of Se through the northern SFB food web in the fall of 1999. One of the challenges that we faced was to quantify feeding relationships in a highly dynamic system that varied spatially and temporally and whose inhabitants were migratory. Stable isotopes were found to be an excellent tool for identifying feeding relationships (carbon $\delta^{13}C$ and nitrogen $\delta^{15}N$) and feeding ranges ($\delta^{13}C$ and sulfur $\delta^{34}S$). By matching $\delta^{13}C$ and $\delta^{15}N$ signatures in predators and prey (assuming a trophic shift of 2.5‰ to 5‰ for nitrogen), two dominant food webs in SFB were identified: crustacean-based and clam-based (*Potamocorbula amurensis*). The most elevated Se concentrations were found in fish species that fed within the clam-based food web. We found that $\delta^{13}C$ and $\delta^{34}S$ at the base of the food web varied spatially and temporally within the northern reach of the estuary (spatial variability was reported in earlier work by Jim Cloern, USGS). Given that "you are what you eat" in terms of carbon and sulfur isotopes, we matched $\delta^{13}C$ and $\delta^{34}S$ signatures of migratory top predators to those of their prey within the estuary. Using these relationships we could explain between 35% and 70% of the variability of Se concentrations in striped bass, sturgeon, splittail, and scaup by the relative amount of time spent feeding on prey in the northern reach of the estuary relative to the Delta. The limited information available on isotopic turnover times in the tissues of large, slow growing predators such striped bass and sturgeon, suggests these results reflect exposures over the six months prior to collection or perhaps longer.

Our next step is to move into the Delta (2001–2004) to better understand the role of hydrodynamics, biogeochemistry and food web dynamics in determining Se levels in biota. Preliminary work done in collaboration with Lenny Grimaldo (DWR) suggests stable isotopes may be equally as helpful within the Delta to identify major routes of trophic transfer and sources of exposure in food webs of the Delta.

Salt Marsh Song Sparrow Feeding Ecology
Letitia Grenier and Steve Beissinger (UC Berkeley)

Originating from the Environmental Science and Policy Management Department at UC Berkeley, our study uses stable isotopes to investigate the feeding ecology of salt-marsh song sparrows. Salt-marsh song sparrows show a great deal of evolutionary differentiation in the San Francisco Bay Area, and they have an unusual ecology for a songbird. We want to understand how tidal influence and microhabitat type affect sparrow food resources. In conjunction with field studies linking sparrow behavior and fitness to habitat variables, we are using stable isotopes of carbon, nitrogen, and sulfur to study the sparrow diet. We plan to map the sparrow food web using tissue samples from primary producers, primary consumers, secondary consumers, and sparrows. Because of the great spatial and temporal variation in primary producer isotope ratios, we may only be able to map the sparrow food web down to primary consumers.

Samples are currently being collected for the second and final year of the stable-isotope study. We have collected field data for this project from 1999–2001 and hope to complete analyses by late 2002.

Identifying the Carbon Sources and Trophic Structure of Fishes in Tidal Wetlands of the Sacramento-San Joaquin Delta
Lenny Grimaldo (DWR and SFSU Romberg Tiburon Center) and Wim Kimmerer (SFSU Romberg Tiburon Center)

The ability to identify and understand the flow of autochthonous and allochthonous sources of carbon between trophic levels is a fundamental component of ecosystem research. With this information, researchers may be able to identify linkages between marsh and channel habitats, assemble aquatic food web models, and assess the value of various restoration efforts for aquatic species. Previous results from the BREACH study (Grimaldo and others, submitted) show the fish assemblages in the Sacramento-San Joaquin Delta are distinctly segregated into littoral and offshore assemblages. The littoral assemblage includes fishes primarily associated with submerged aquatic vegetation (SAV) and the offshore assemblage include zooplantkivorous fishes that are found in deep channels and open water environments. Given these two assemblages occupy separate areas of the tidal wetland gradient, we hypothesize that the sources of carbon and the trophic structure of fishes differ between these assemblages. Along with general life history information (ecology and physiology) and a diet analysis of the fishes, we are using stable isotope analysis to elucidate the food web pathways of the littoral and offshore assemblages. In particular, we hope to reveal the importance of dominant primary consumers in supporting the two fish assemblages. We believe this IEP-funded study will provide valuable information and insight on the constructs of the Delta food web. This study should help scientists and managers evaluate the effects of restoration strategies, contaminants and introduced species in the Sacramento-San Joaquin Delta.

In collaboration with Robin Stewart (USGS), we have already collected samples of primary producers, invertebrates and fishes from Mildred Island (central Delta), Venice Cut Island (central Delta) and Sherman Island (western Delta). Because we expected temporal variability in the isotopic signatures of the samples due to fractionation, we collected summer and winter samples to document potential variation among seasons. We expect to complete lab analyses by June 2001.

Origin and Migration of Central Valley Chinook Salmon as Determined by Otolith Geochemistry
Peter K. Weber and B. Lynn Ingram (UC Berkeley), and Ian D. Hutcheon (Lawrence Livermore National Laboratory)

Under funding from the California Department of Water Resources, we are developing methods to identify the river of origin and juvenile migration history for chinook salmon in the Sacramento-San Joaquin river system using otolith chemistry. Otoliths are calcium carbonate structures in the inner ear of bony fish that grow continuously throughout the life of the fish and have daily banding in juvenile salmon. If otolith chemistry can be uniquely related to specific rivers and regions in the watershed, the life history of the fish can be reconstructed. This approach would be broadly useful for the management and study of chinook salmon and other fish species. In emigrating juveniles, this approach could be used to distinguish endangered and threatened stocks in the Delta. In returning adults, it could be used to determine successful rearing strategies, straying rates, and relative abundance of wild and hatchery spawners.

Isotopic markers have proven to be particularly informative for this work. We have shown that strontium isotopic composition ($^{87}Sr/^{86}Sr$) of the otolith is a distinctive indicator of watershed origin (Ingram and Weber 1999). Our recent work has shown that sulfur isotopic composition ($\delta^{34}S$) of the otolith can be used to distinguish hatchery and wild salmon (in review). Our preliminary data suggest other stable isotopes can provide additional information on downstream migration and temperature history and serve as a cross-check for watershed origin. We are currently developing microchemical analytical techniques applicable to the scale of otolith banding (5 to 20 microns), and we are working to characterize the spatial and temporal variability of these markers in the Sacramento-San Joaquin river system.

Behind the Energetics of the Asian clam, *Potamocorbula amurensis* in San Francisco Bay
Janet Thompson, Robin Stewart, and Francis Parchaso (USGS)

The Asian clam (*Potamocorbula amurensis)* has played a key role in the food web of northern San Francisco Bay since its invasion in the fall of 1986. It has been associated with a dramatic decline in primary production, loss of a zooplankton species and a native mysid shrimp, the probable decline in striped bass, and has introduced alternative pathways for contaminant cycling in the bay food web. Given the far-reaching effects of this species, a research program was designed to answer basic questions about the population characteristics of this invasive clam. For the past 13 years, benthic grabs were taken monthly at sites throughout the northern reach of the bay from which population attributes of the clams could be determined. Population differences in recruitment, growth, condition, and mortality were thought to be due, in part, to differences in food quality and food availability. To test this hypothesis, stable isotopes of carbon and nitrogen were measured in the soft tissues of clams from nine different sites from July 1999 to June 2000. This approach assumes that the isotopic signature of the clams reflects the diet of the clam over the previous month (confirmed by growth-metabolic model). Sites were chosen to answer such questions as, “How does hydrodynamics determine the dominant food source used by the clams/” and “Can different food sources could be linked to different population responses?” Isotope data on clams collected at USGS Polaris station 8.1 in Carquinez Strait in 1993, 1994, and 1999 are being examined to determine inter-annual variability in isotopic signatures of the clams.

Preliminary results show a strong relationship between clam carbon isotopic signature and proximity to Delta water, and strikingly similar seasonal patterns among stations for both carbon and nitrogen isotopes, with a few interesting exceptions. We are currently developing models to test the contribution of *in situ* phytoplankton production to the clam diet.

Breached-Levee Wetland Studies in the Sacramento-San Joaquin Delta (BREACH) and San Pablo and Suisun Bays
Charles "Si" Simenstad (University of Washington)

In our interdisciplinary CALFED studies of breached-levee restoration and nearby natural (reference) sites in the Sacramento-San Joaquin Delta and portions of the San Francisco Bay, we are (1) assessing hydrological, geomorphological, biogeochemical and ecological indicators at diverse, differently-aged sites of formerly leveed wetlands that have historically reverted to tidal inundation; (2) comparing indices of ecological and general fish and wildlife habitat quality of these naturally breached levee sites to existing mitigation and restoration sites that were purposefully constructed by levee breaching or comparable restoration actions; and, (3) using the same indicators, assessing the status of these restored wetlands to wetland function at natural "reference" marsh sites. One suite of indicators will use natural stable isotopes to evaluate the degree to which restoring marsh food webs are relatively "closed" or linked to terrestrial or bay organic matter sources. We will assess the stable isotope signatures ($\delta^{13}C$, $\delta^{13}N$, and $\delta^{34}S$) of representative (representative feeding type; widely distributed) consumer organisms fishes and macroinvertebrates, and of the most likely organic matter sources to the food web (such as riverine input, phytoplankton, benthic microalgae, SAV, emergent wetland vegetation) that have not already been determined by CALFED and other ongoing research projects. We will adapt a statistical multiple tracer mixing model (Lubetkin and Simenstad, submitted) to estimate the relative proportions of organic matter supporting these consumer organisms through various autochthonous or allochthonous food web pathways.

Accordingly, these studies are organized to address the following ecological questions, and premises or hypotheses, about the short- and long-term role of emergent estuarine marshes in the Bay-Delta:

1. Are resident biota in restoring marshes dependent more on external (bay phytoplankton-based) production than ancient and centennial marshes?
    - Food web linkages in established marshes are based on "internal" macrophyte detritus pathways.
    - Biota in early "mudflat" stages of restoring marshes are dominated by edaphic microalgae isotopic signatures.
    - Prolonged stages of flooded Delta islands have developed freshwater phytoplankton and submerged aquatic vegetation signals.
2. Is there a gradient in terrestrial-marine organic matter influence between Delta and western San Pablo Bay?
    - Tidal advection of organic matter overwhelms more local macrophyte-based signatures.
3. Do transient (fish) species known to use marshes have marsh food web isotopic signatures?
    - Marsh production supports transient fishes; marshes provide food web linkages to the bay vis a vis "trophic relay."
    - Restoring marshes provide primarily non-trophic function; alternatively, edaphic microalgae provide alternate food web pathways.

However, to maximize the efficiency of these analyses and comparability to other food web studies in the Bay-Delta, it is important to at least identify, if not coordinate with, other stable isotope information that is being acquired from the system. For instance, before finalizing our sampling design and priorities for stable isotope analyses, we would like to ascertain the following:

- What is the extent of documented $\delta^{13}C$, $\delta^{15}N$, and $\delta^{34}S$ signatures for all possible organic matter sources?
- Are the terrestrial and marine "end members" well documented?
- What is the documented spatial and temporal variability of the predominant sources?
- What representative or "indicator" biota have other studies used?
- What are candidate trophic types of consumers, for example, pelagic and benthic suspension feeders, benthic deposit feeders, primary and secondary predators, etc.?
- How can we help fill gaps in isotopic source characterization?
- Is anyone looking for indicators of the role or extent of heterotrophic pathways?

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Use of Stable Isotopes to Examine the Food Webs of Yolo Bypass and Sacramento River

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In recent years, stable isotopes have been increasingly used as a tool to understand trophic relationships in different habitats (Gearing 1991; Fry 1999). Two of the most frequently used isotopes are nitrogen (^{15}N/^{14}N or δ^{15}N) and carbon (^{13}C/^{12}C or δ^{13}C). Levels of δ^{15}N are enriched in the upper trophic levels of food webs, allowing relative trophic position to be inferred from isotopic results (Vander Zanden and others 1997). Levels of δ^{13}C are often comparable between consumers and their food sources, providing a tool to help identify the energy base supporting different food webs (Gearing 1991).

In 2000 we did a preliminary study on stable isotopes to try and better understand the food webs of the Yolo Bypass floodplain and the adjacent Sacramento River channel. Our previous studies demonstrated there were major differences in invertebrate abundance, and salmon diets and feeding success between the two habitats (Sommer and others 2001). We reasoned that these results might reflect major differences in trophic structure that would be detectable using stable isotopes. Another rationale for the study was to provide insight into the trophic ecology of large river systems. For instance, under the "flood pulse concept," Junk and others (1979) predict that most of the energy for large rivers originates from terrestrial inputs from floodplain habitat rather than *in situ* phytoplankton production.

Our specific objectives were to determine whether (1) stable isotope ratios help to describe the food webs of the Yolo Bypass and Sacramento River; (2) isotopic data are consistent with life history patterns of different organisms; and (3) there are major differences in the food web structure of floodplain and river channel habitat. We hypothesized that stable isotope signatures should be different between the two habitats as a result of greater inputs of terrestrial carbon and increased abundance of primary consumers (invertebrates) on the floodplain.

Methods

Our sampling focused on a high flow period during February and March 2000 when the Yolo Bypass was inundated. Samples were concurrently collected at sites in the Yolo Bypass (Interstate 5 bridge and screw trap site near little Holland Tract) and Sacramento River (Elkhorn Boat Ramp and Clarksburg). The samples were collected at each site using methods similar to Thorpe and others (1998). To analyze terrestrial inputs to each food web, we collected samples of C3 and C4 plants from the dominant terrestrial plant species including grasses and cottonwoods. Aquatic energy inputs were evaluated based on (1) seston samples, bulk water samples (size fractionated for transported organic matter), particulate stored (benthic) organic matter, and dissolved organic matter; (2) rooted aquatic macrophytes (tules); and (3) periphyton scraped from aquatic macrophytes, logs and rocks. Several consumer groups were also analyzed. Zooplankton were collected using Clarke-Bumpus nets, then copepods and cladocerans were separated using a dissecting microscope. Aquatic insects (odonates, chironomids and corixids) were collected using drift and hand nets. We also collected clams (*corbicula*) from Putah Creek, then placed them in mesh cages in each of the sampling areas. Mollusks have previously been used as lower trophic level “integrators” to help correct for variation in the stable isotope signatures at the base of the food chain (Vander Zanden and others 1997). Mollusks were not widespread in each of the sampling areas, so stocking was required for this analysis. Secondary consumers including juvenile salmon (CWT tagged hatchery released and wild fish) and inland silverside were collected using beach seines.

Samples were frozen after the guts of the target organisms were cleared by overnight depuration in clean water (invertebrates) or dissection (fish muscle tissue). Defrosted samples were oven dried, ground with a mortar and pestle, weighed, then wrapped in tin capsules. All samples were analyzed at the UC Davis stable isotope facility by Dr. David Harris (see on-line information at http://stableisotopefacility.ucdavis.edu).

Major Findings

Variability in the Isotopic Results Made It Difficult to Identify the Food Webs in Each Habitat

Although $\delta^{15}N$ values were variable, the results followed the expected patterns of trophic position (Figure 1). There were low $\delta^{15}N$ values for the primary producers (grass, trees, periphyton, tule), intermediate levels for invertebrate consumers, and highest levels for fish. However, extreme variability in the $\delta^{13}C$ results made it difficult to identify carbon sources for consumers. In simple idealized food webs, we expect that the carbon sources should align vertically with $\delta^{13}C$ signatures of their consumers. In our case, the $\delta^{13}C$ signatures of most of the invertebrate consumers overlapped with at least two primary producers, perhaps because these consumers rely on multiple carbon sources. However, the standard deviations of the primary producers were relatively large, so we could not differentiate between actual linkages and sample variability.

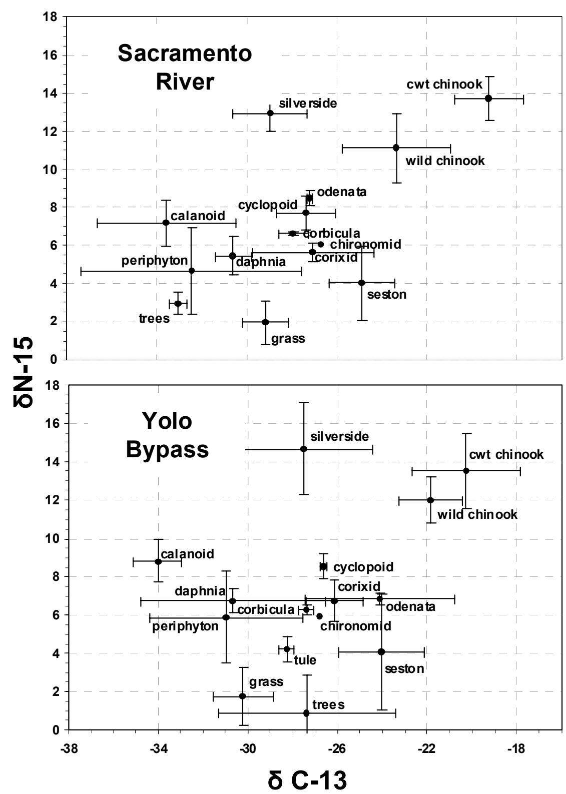

Figure 1 Stable isotope results for different organisms in Yolo Bypass and Sacramento River during a February-March 2000 high flow event. The means (dots) and standard deviations (vertical or horizontal solid lines) are shown.

Some of the Isotopic Patterns Are Consistent With Life History Patterns

The introduced inland silverside and native chinook salmon are frequently the most abundant fish species during winter in the Yolo Bypass and Sacramento River; their young apparently share the same opportunistic, "picking" feeding strategy (Moyle 1976). Yet our results showed that these two fish had markedly different $\delta^{13}C$ signatures. The isotopic signatures of silverside overlapped with those of *Daphnia*, cyclopoids, and chironomids (Figure 1), consistent with Moyle's (1976) observation that silverside feed primarily on larger zooplankton species and planktonic insects. By contrast, the $\delta^{13}C$ levels of wild and hatchery salmon were much higher. With the exception of wild fish in the Sacramento River, the $\delta^{13}C$ levels did not overlap with zooplankton or chironomids, the two major food sources (Sommer and others 2001). The fact that the $\delta^{13}C$ levels in the hatchery fish were different from silverside is reasonable because these salmon were raised on hatchery diets containing large amounts of marine carbon (such as fish meal). We believe the unexpectedly high $\delta^{13}C$ levels in the wild salmon may be a result of their history before they entered the Delta. Inspection of isotopic signatures for individual juvenile salmon showed that there was a general pattern towards decreasing $\delta^{13}C$ and $\delta^{15}N$ levels with larger fish (Figure 2). One interpretation of these results is that the food web in Delta tributaries could be heavily influenced by marine carbon from the carcasses of the adult spawners. Under this hypothesis, the isotopic signature of emigrating juvenile salmon would show a gradual shift from "imported" marine carbon in the tributaries towards "locally produced" carbon sources as they entered downstream riverine and floodplain habitats. Major effects of carbon from carcasses on food webs have been noted by many other studies of salmon streams (Bilby and others 2001). As an indication of the potential effects of parental carbon, during 2000 a short reach (9 miles) of the lower Feather River received an energy subsidy of roughly 850 tons of carbon from salmon carcasses (DWR unpublished data).

We Found No Evidence of Major Differences Between the Yolo Bypass and Sacramento River Food Webs

There were no obvious differences in the isotopic signatures of consumers in Sacramento River and Yolo Bypass (Figure 1). It is possible that high variability could be masking actual differences in the food webs between the two habitats. However, there are several reasons to expect that there may not have been major differences in energy pathways between the two habitats. First, our samples were collected during a one-month flood event, which may not have been sufficient time for consumers to develop distinct stable isotope signatures. Longer flood events (greater than 30 days, such as in 1997 or 1998) might produce greater differentiation in the $\delta^{13}C$ and $\delta^{15}N$ levels. Even if there are distinct "riverine" or "floodplain" isotopic signatures, our study may not have been able to detect these effects because of the confounding upstream influence of Sutter Bypass. The Sutter Bypass floodplain flows into both the habitats we studied, so each may show a strong influence of floodplain energy inputs.

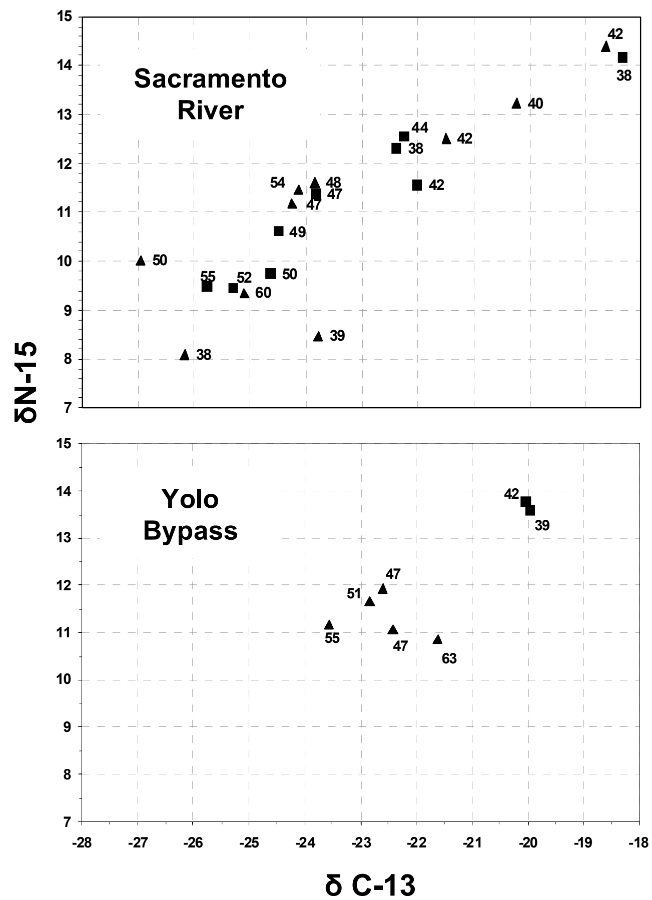

Figure 2 Isotopic signatures for wild juvenile chinook salmon collected in Sacramento River and Yolo Bypass during February (square symbols) and March (triangle symbols) 2000. The symbols are labeled with the fork lengths (mm) of each fish analyzed

Recommendations

Although our study yielded some interesting results, we were not able to fully answer our primary study questions. It is possible that there were no substantial differences between the floodplain and riverine food webs; however, this issue cannot be resolved until we determine why variability was so high in our samples. Stable isotope results from aquatic habitats in other regions suggest isotopic signatures in Delta food webs are unusually variable (Jake Vander Zanden, personal communication). Therefore, our major recommendation is that more spatially and temporally intensive sampling be conducted to examine the sources of variability in isotopic signatures. We also believe that additional research is needed on upstream food webs. The temporal pattern of isotopic signatures in juvenile salmon provides evidence that salmon carcasses could represent a substantial energy subsidy for the tributaries and perhaps the Delta.

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Notes

Jake Vander Zanden. University of Wisconsin. Conversation with Ted Sommer in May 2001.

Phytoplankton and Nutrient Dynamics in Suisun, San Pablo, and Central Bays

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Introduction

As part of an EPA-funded project to develop indicators of ecosystem condition, monthly cruises to Suisun, San Pablo, and Central San Francisco bays began in November 1999 to monitor several oceanographic variables, including chlorophyll-*a* concentration. We observed increases in chlorophyll-*a* concentrations above the annual mean during October 2000 and in April of 2000 and 2001. These increases followed decreases in ambient ammonium and nitrate concentrations. During April chlorophyll-*a* was comprised primarily of phytoplankton cells greater than 5 µm in diameter. These chlorophyll-*a* concentrations almost match the pre-*Potamocorbula* summer peaks in chlorophyll-*a* (30 to 40 µg/L) observed in the 1970s and early 1980s (Alpine and Cloern 1992), which indicates that phytoplankton may be recovering from the initial grazing devastation. The elevated chlorophyll-*a* concentrations would have been missed if weekly sampling had not been included during the "bloom" months, and lends support to monitoring these areas with moored fluorometers.

Sites and Methods

Suisun Bay (USGS Station 6), San Pablo Bay (USGS Station 13), and Central Bay (a station chosen in the channel in front of the Romberg Tiburon Center) were sampled during this study (Figure 1). All stations were similar in water column depth and ranged from 8 to 10 m. A Seabird CTD measured salinity, temperature, and depth. Samples to assess chlorophyll-*a* concentration in different phytoplankton size classes (whole community and greater than 5 µm and 10 µm in diameter) were collected and measured by fluorometry using a protocol (Venrick and Hayward 1984) adapted from Hansen and others (1965). Nitrate and silicate concentrations were determined using a Technicon Autoanalyzer II according to the procedures of Whitledge and others (1981) and ammonium samples were measured using a Hewlett Packard diode array spectrophotometer and 10-cm cell according to the method of Solorzano (1969). This article describes the surface changes in these physical and biological variables in Suisun, San Pablo, and Central bays since November 1999.

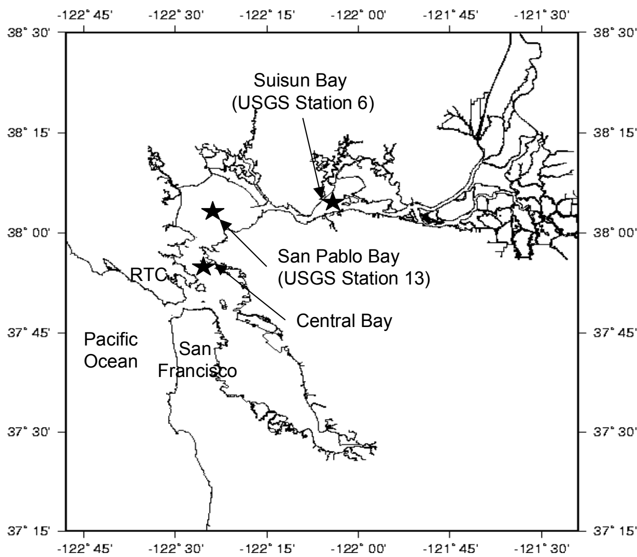

Figure 1 A map of the study site and stations within Suisun (USGS Station 6), San Pablo (USGS Station 13) and Central bays (a station chosen in front of the Romberg Tiburon Center)

Temperature and Salinity

Surface temperature was less variable between study sites than was surface salinity (Figure 2). Temperatures ranged between 9.1 and 22 ºC over the time series and were lowest during the winter with increased temperatures in the summer months. All three study sites showed the lowest temperatures in January of 2000 and 2001. Temperatures were 9.1 ºC in Suisun Bay, 10.2 ºC in San Pablo Bay, and 10.5 ºC in Central Bay in 2000 and 9.5 ºC, 10.2 ºC, and 10.9 ºC, respectively, in 2001 (Figure 2A). Surface water temperatures increased in spring, with a range of 13 ºC to 16 ºC, and continued into summer, with Suisun Bay exhibiting 22 ºC in August 2000 and San Pablo and Central bays registering 20 ºC and 19 ºC, respectively. A similar range of 17 ºC to 22 ºC was measured in August 2001.

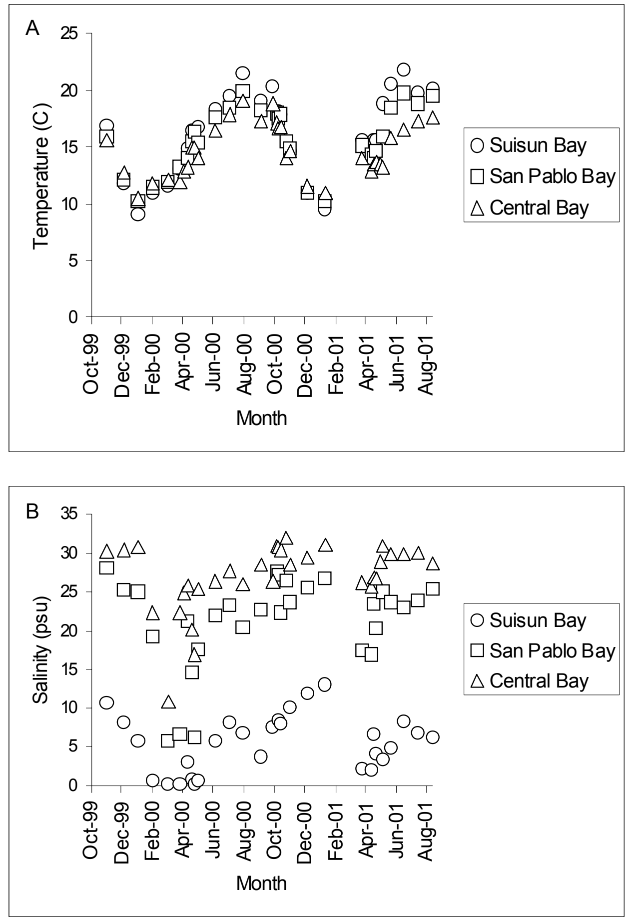

Figure 2 Surface temperature and salinity values from October 1999 through August 2001 in Susiun, San Pablo, and Central bays

Salinity values were more variable between study sites (Figure 2B). Salinity in Suisun Bay was lower than in San Pablo and Central bays in 2000 and 2001, indicating the freshwater influence from the Delta. Suisun Bay salinity values ranged from 10 to 13 psu in the winters of 1999–2000 and 2000–2001. The lowest salinity value (0.2 psu) in Suisun Bay was observed on April 25, 2000. In spring 2001, Suisun had slightly higher values in spring 2000 ranging from 2 to 7 psu, but still lower than fall or winter. Lower salinity values of a wider range also were observed in spring 2000 in San Pablo Bay (6 to 21 psu) compared to 17 to 23 psu in spring 2001. San Pablo Bay and Central Bay were more saline than Suisun Bay, reaching 30 psu during spring 2000 and 2001 in Central Bay. The winter months showed a wider range of salinity (22 to 32 psu), influenced by storm activity and freshwater inputs from North Bay on the Central Bay.

Phytoplankton Biomass and Size Fractionation

Phytoplankton biomass (chlorophyll-*a*) for the entire community was measured using a GF/F filter (nominal pore size, 0.7 µm) and for fractionated cells >5 µm and >10 µm diameter using specific pore-sized nucleopore filters. Phytoplankton biomass increased in spring 2000 and 2001 and was tracked with weekly shipboard sampling (Figure 3). This increase occurred both years in San Pablo and Central bays, but was not apparent in Suisun Bay in spring 2001, when two weekly samplings at the end of April were missed. Slightly elevated chlorophyll-*a* concentrations also were detected in fall 2000 at all three locations, which prompted weekly sampling; however, the increase was not as significant as observed in the spring.

Chlorophyll-*a* concentrations for the entire community ranged from approximately 1 to 2 µg/L throughout most of 2000 and 2001 (Figure 3A) at all three study sites. The elevated concentrations during the spring (April) and fall (October) showed the most pronounced increase in Suisun Bay with a chlorophyll-*a* concentration of 30 µg/L in spring 2000. San Pablo Bay values at this time ranged from 5 to 15 µg/L and Central Bay had a lower range of 4 to 7 µg/L. By mid-May 2000, chlorophyll-*a* concentrations had returned to 1 to 2 µg/L. In spring 2001, the peaks in chlorophyll-a in San Pablo (16 µg/L) and Central bays (13 µg/L) were higher than those in the spring 2000 (Figure 3A).

Fractionated chlorophyll-*a* concentrations (>5 µm and >10 µm) showed that the proportion of larger cells in the total phytoplankton community varied throughout the year (Figures 3B and 3C, and Table 1). When phytoplankton biomass was high in spring 2000 and 2001, the phytoplankton community was generally dominated by larger cells—that is, >60% of the total chlorophyll-*a* were due to these cells. Slightly elevated chlorophyll-*a* concentrations also were observed in fall 2000. However, fractionated chlorophyll-*a* values showed larger cells contributed 30% to 40% of the total chlorophyll-*a*, indicating a difference in the proportion of larger cells in the phytoplankton community in the spring and fall.

Table 1 The percentage of the phytoplankton community greater than 5-µm diameter

Date[a]	Suisun Bay	San Pablo Bay	Central Bay
January 2000	61	39	97
February 2000	21	39	34
March 2000	31	36	55
March 28, 2000	57	100	100
April 4, 2000	n/a	91	73
April 20, 2000	100	100	80
April 25, 2000	62	83	93
May 2, 2000	90	100	94
May 10, 2000	n/a	47	48
May 16, 2000	72	61	n/a
June 2000	73	n/a	57
July 2000	82	100	72
August 2000	69	100	58
September 2000	54	65	54
September 9, 2000	65	29	84
October 6, 2000	n/a	16	98
October 10, 2000	5	26	100
October 16, 2000	48	27	32
October 26, 2000	n/a	37	83
November 2000	43	47	46
December 2000	60	33	57
January 2001	54	94	83
February 2001	75	63	50
March 2001	82	72	64
April 13, 2001	100	67	84
April 19, 2001	81	59	80
April 24, 2001	85	100	100
April 25, 2001	n/a	96	n/a
May 2, 2001	n/a	80	74
May 7, 2001	60	100	94
May 22, 2001	75	30	61
June 2001	68	46	58
July 2001	71	41	23
August 2001	70	35	31

a. Sampling was conducted monthly, except in spring and fall when sampling was conducted weekly, as indicated by the exact dates given in this table.

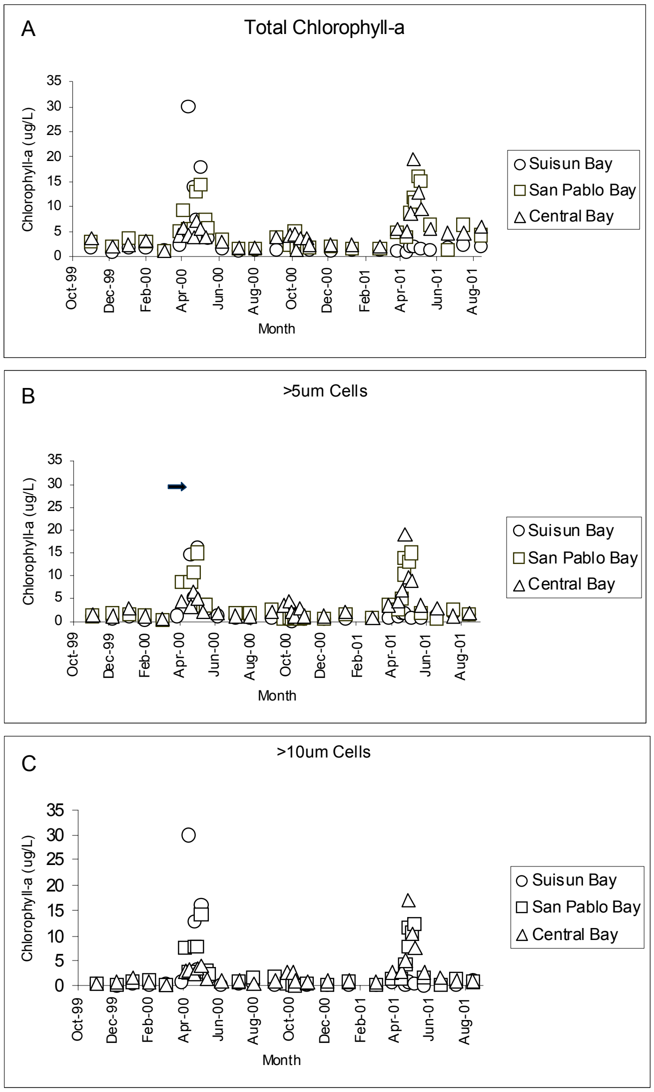

Figure 3 Surface chlorophyll-*a* concentrations (μg/L) measured for (A) the entire phytoplankton community and for phytoplankton cells (B) >5-μm diameter and (C) >10-μm diameter. The arrow in Figure 3B indicates a sample lost during analysis and an estimate of the value of that sample based upon total community and >10-μm cell diameter values.

Nutrient Concentrations

Nutrient concentrations in San Francisco Bay were consistently high and at seemingly non-limiting concentrations (Figure 4). Nutrient concentrations were highest in Suisun Bay and decreased in a seaward direction toward Central Bay. Over the annual cycle, temporal ammonium and nitrate concentrations decreased in the spring (Figures 4A and 4B), preceding the increase in chlorophyll-*a* biomass. The growth of phytoplankton was likely responsible for the measured decrease in dissolved inorganic nitrogen (DIN) concentrations, which, in turn, was assimilated into phyplankton particulate nitrogen. Decreases in DIN concentrations also were detected in the fall, but to a lesser extent than measured in the spring.

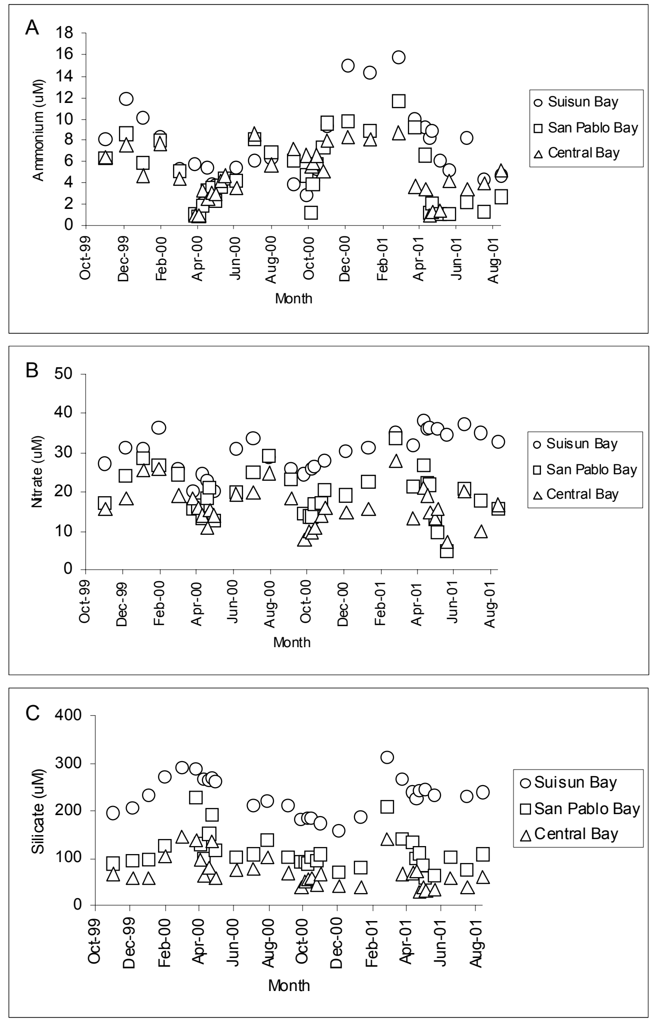

Figure 4 Surface (A) ammonium, (B) nitrate, and (C) silicate concentrations (μM, micromolar) measured in Suisun, San Pablo and Central bays

In spring 2000, ammonium concentrations in Suisun Bay decreased from 16 μM to 2 to 5 μM. Similarly, concentrations in San Pablo and Central bays dropped to 1 to 4 μM and 1 to 3 μM, respectively (Figure 4A). Ammonium concentrations increased during summer 2000, reaching a maximum of 9 μM, then decreased again in fall 2000. Similar trends were observed the following year: ammonium concentrations dropped to 1 μm in San Pablo and Central bays during spring 2001. Although

Suisun Bay did not show a marked increase in phytoplankton biomass in spring 2001, ammonium concentrations in this bay still decreased from 16 µM to 6 µM supporting the idea that a chlorophyll-*a* increase might have occurred following this decrease. However, we were unable to sample Suisun Bay during the following weeks when this may have occurred.

Nitrate concentrations in Suisun Bay were high in winter 1999–2000 (27 to 37 µM) before decreasing to 20 µM in the spring (Figure 4B). San Pablo and Central bays experienced similar trends of 17 to 29 µM and 16 to 26 µM in winter 1999–2000 before decreasing to 13 µM and 11 µM, respectively, in the spring. We observed a greater decrease in nitrate concentrations in spring 2001 to 5 µM in San Pablo Bay and 7 µM in Central Bay. Unlike the previous spring, nitrate concentrations remained high (32 to 38 µM) in Suisun Bay in spring 2001.

Silicate concentrations showed similar seasonal changes, but with spatial differences—we measured greater values in the north that decreased seawards toward Central Bay (Figure 4C). During winter months, silicate concentrations in Suisun Bay reached 270 µM in 2000 and 312 µM in 2001. Concentrations in San Pablo Bay reached to 200 µM, whereas Central Bay values only reached 140 µM. Matching the decreasing DIN concentrations, all three study sites showed decreases in silicate concentrations in spring 2000 and 2001. As phytoplankton biomass increases, larger cells (such as diatoms, which require silica to grow), tend to dominate (Table 1),which may contribute to the decrease in silicate concentrations.

Discussion

The physical and biological factors monitored since November 1999 and described here show definitive seasonal trends in North and Central San Francisco bays. Surface water temperatures are lower in fall and winter and increase in spring and summer, with associated changes in phytoplankton biomass. For example, chlorophyll-*a* concentrations increased in spring when surface water temperatures were not at extreme (high and low) levels and when salinity was lowest, thereby creating ideal conditions for stratification. This stability in the water column ensured that phytoplankton were retained in the illuminated surface waters and could grow, as indicated by the elevated chlorophyll-*a* values measured during spring 2000 and 2001.

Elevations in phytoplankton biomass were also observed in October 2000, possibly a result of water column stratification as water temperatures cooled after summer. These elevations were similar to those observed in spring 2000. However, the availability of light during this time may restrict the phytoplankton response. Storm patterns and greater cloud coverage associated with fall weather conditions could affect the quality of light reaching phytoplankton cells, thus negatively affecting photosynthesis. Another possibility is that the seed population of phytoplankton consisted of small cells, which typically take longer than diatoms to reach bloom concentrations.

The growing phytoplankton biomass apparently used ammonium as a primary nitrogen source, since a decrease in ammonium concentrations accompanied the increase in chlorophyll-*a* concentrations (Figure 5). Ammonium concentrations were lowest during spring and fall, coinciding with increased phytoplankton biomass. The phytoplankton community may use nitrate once ammonium has been depleted to less than 1 µm and any inhibition by ammonium on nitrate uptake is lifted. Nitrate concentrations never dropped as low as ammonium concentrations (Figures 5 and 6).

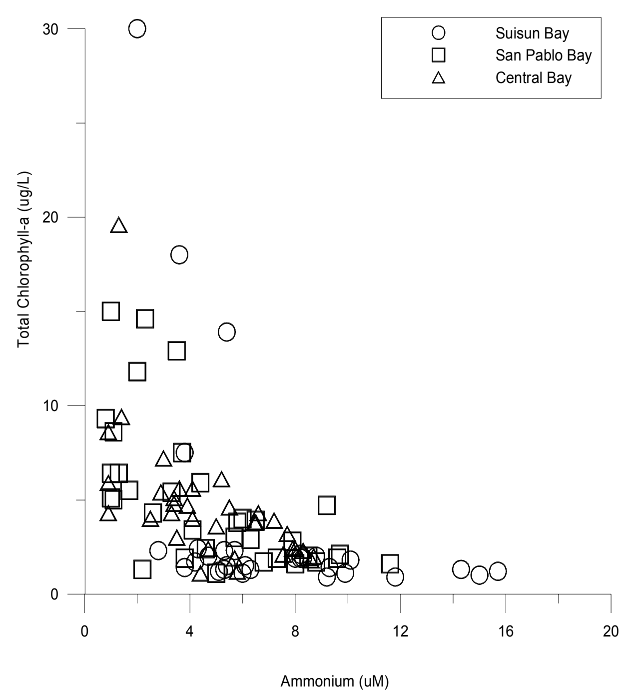

Figure 5 Surface chlorophyll-*a* concentrations (µg/L) for the entire phytoplankton community versus surface ammonium concentrations (µM) in Suisun, San Pablo, and Central bays

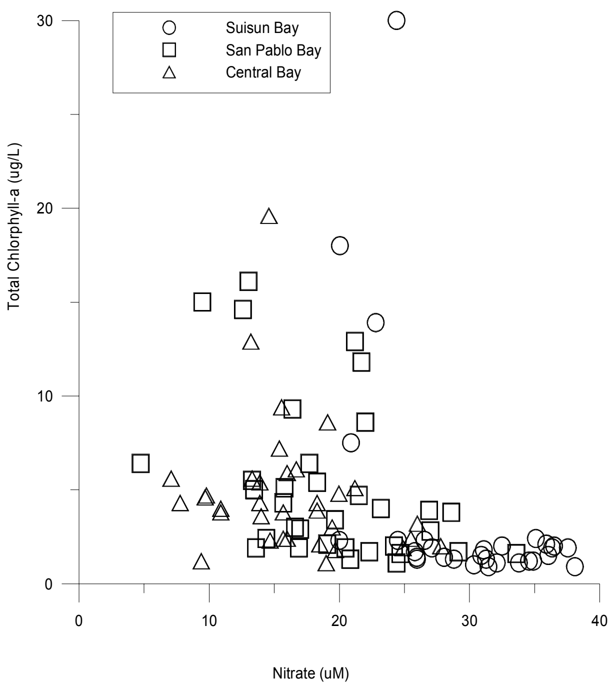

Figure 6 Surface chlorophyll-*a* concentrations (µg/L) for the entire phytoplankton community versus surface nitrate concentrations (µM) in Suisun, San Pablo, and Central bays

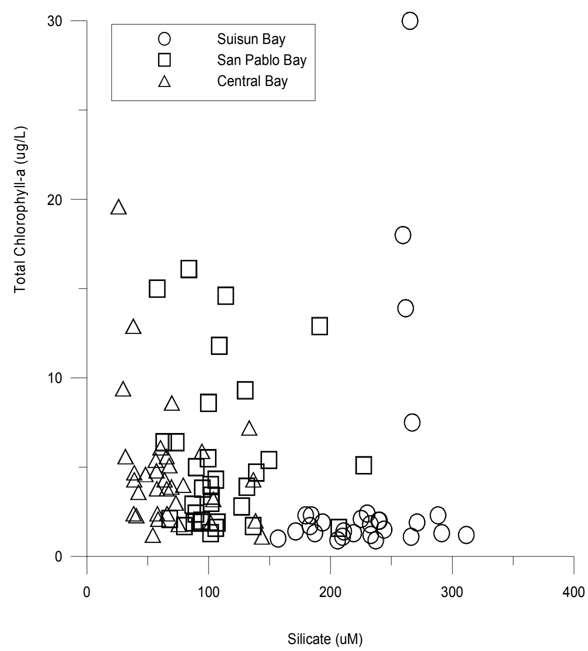

Figure 7 Surface chlorophyll-a concentrations (µg/L) representing the entire phytoplankton community versus surface silicate concentrations (µM) in Suisun, San Pablo, and Central bays

The nitrate and silicate concentrations available even during periods of high phytoplankton biomass suggests nutrients are in non-limiting concentrations (Figures 6 and 7). The fractionated chlorophyll-*a* data indicate that as phytoplankton biomass increases, larger cells, most likely diatoms, dominate the phytoplankton community (Table 1). Therefore, as the phytoplankton community grows, a decrease in silicate would be expected. However, we observed higher silicate concentrations when chlorophyll-*a* concentrations were also high (Figure 7). Freshwater from the Delta may provide a constant and saturating supply of silicate to these study sites; so as the phytoplankton community removes it from the water column, the supply is quickly replenished.

This EPA-funded project, when originally proposed, called for monthly sampling. However, if additional weekly sampling had not been conducted in spring 2000, high chlorophyll-*a* concentrations may not have been detected (Figure 3). In spring 2000 and 2001, the highest phytoplankton biomass concentrations were measured on days that fell between scheduled monthly sampling dates. We may have missed detecting a peak in chlorophyll-*a* concentration during late April in Suisun Bay. Missing data may explain the “lack” of a chlorophyll-*a* increase in Suisun Bay similar to those observed in San Pablo and Central bays. Since dramatic changes at these study sites can occur on short time-scales, sampling should take place weekly, if not daily, to accurately evaluate the primary production in San Francisco Bay.

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Can Hokkaido Herring Add to Our Understanding of the Reproductive Requirements of Herring in San Francisco Bay?

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Introduction

Adult Pacific herring (*Clupea pallasi*) inhabit marine waters over the continental shelves of the northern Pacific Ocean from Japan to California, in the Bering Sea, and portions of the Arctic Ocean. Annually, reproductive adults migrate into protected intertidal and shallow subtidal areas primarily in estuaries or bays where spawning, fertilization, embryonic development, and larval development occur. Passage through these early life stages can take six and a half to seven months of the first year of a herring's life, during which they are dependent on estuarine conditions. Pacific herring, because of their early life stages, are acknowledged to be ecologically important to estuarine ecosystems and are currently being considered an essential species in different regions of their range because of the complex role they play in both estuarine and marine systems.

They are also economically important to an international fishery that targets reproductive animals to collect ovaries (Kazunoku) and spawned eggs attached to kelp (Kazunoku Kombu) for consumption in the Japanese market. Juveniles and some adults are taken either in a bait fishery or for sale as fresh or salted herring but these takes are not major. Much information exists on the biology of Pacific herring because of their economic and ecological importance. One of the major tenants emerging from this information is that Pacific herring are not a homogeneous group.

Because of the disparate climates that exist throughout the species' range, the estuaries where they reproduce differ considerably with regard to water temperature and salinity. Water temperature measurements from spawning sites in the Sea of Japan, Sea of Okhotsk, Barents Sea, and the White Sea ranged from –0.5 to 8 °C while salinity varied from 10 to 36 ppt (Dushkina 1973). Water temperatures in San Francisco Bay have ranged from 8 to 14 °C and salinity from 4 to 32 ppt during the spawning season (unpublished data). Spawning over the species geographical range has been reported at temperatures ranging from 0 to 20 °C and salinity from 4 to 33 ppt (Grosse and Hay 1988; T. Matsubara, personal communication). Optimal conditions are reported to be in the low end of the range for water temperature, 5 to 9 °C, and the mid-range for salinity, 16 ppt (Alderdice and others 1979). From these observations, we find that embryos and larvae can withstand broad temperature and salinity regimes. However, spawning success over these ranges have not been established. Do smaller percentages of embryos complete embryonic and larval development outside non-optimal temperatures and salinity, and is any reduction significant to the population? Additionally, the temperature and salinity regimes under which individuals of different populations can develop are not well documented. Does a population possess individuals with a range of developmental temperature and salinity tolerance and, if so, is this diversity important to a population? We believe that answers to these questions are important to understanding herring reproduction throughout the species range and may be critical to understanding that of the San Francisco Bay population given that the bay is currently the effective edge of the species' range and presents a highly variable environment for Pacific herring early life stages.

Over the last two years our laboratory has collaborated with scientists from San Francisco State University, the University of Tokyo, the Hokkaido National Fisheries Research Institute, the California Department of Fish and Game and the Japan Sea Farming Association (JSFA), to understand salinity effects on herring reproduction and larval growth and survival. A portion of the research focuses on salinity tolerances of gametes, embryos, and larvae from San Francisco Bay, while another segment examines populations or stocks of herring from Lake Akkeshi (Akkeshi-ko), in Hokkaido, Japan. We collaborated with Dr. Takahiro Matsubara of the Hokkaido National Fisheries Research Institute and Mr. Yoshihisa Yamamoto of the JSFA on the Japan-based project because it offered us the opportunity to investigate a population distinct from that of San Francisco Bay under conditions that allowed large-scale controlled incubations and manipulations of embryonic and larval development conditions. As described below, using Akkeshi-ko herring may provide clues as to the elasticity of salinity tolerance and the mechanisms that determine it.

Salinity and Reproduction in Pacific Herring

Since the 1950s researchers have been aware that herring reproduction is influenced by salinity. Professor RyuzoYanagimachi first described sperm motility and fertilization in Pacific herring at the University of Hokkaido, Japan. He demonstrated that elevated salinity negatively affected sperm function and fertilization. Yanagimachi noted that the ionic strength of the seawater influenced the ability of sperm to activate and fertilize an egg. Sperm in dilute seawater (about half-strength, 15 ppt), although immotile until they made contact with an egg, were able to fertilize eggs for more than 24 hours. Sperm placed in full strength seawater, however, were not viable (Yanagimachi 1953; Yanagimachi and Kanoh 1953). These findings were revisited by Gary Cherr (UC Davis, Bodega Marine Laboratory), Murali Pillai (Sonoma State University), and Ryuzo Yanagimachi (University of Hawaii), who furthered the early research. We now know that the optimal salinity range for fertilization and embryonic development of San Francisco Bay herring is about 12 to 24 ppt seawater, with optimal salinity at 16 ppt (Griffin and others 1998).

Herring are broadcast spawners; females release eggs that are surrounded by a tough impenetrable coat that adheres to algae, other marine plants or hard substrates. Development from first gamete contact at spawning through the arrival at the juvenile stage takes approximately 6 to 8 weeks. Males release immotile sperm into the water and fertilization occurs (Figure 1) when they make contact with an egg. Planktonic larvae hatch 10.5 days after fertilization at 10.5 °C in San Francisco Bay (Eldridge and Kaill 1973). In the laboratory, larvae hatched over a protracted period of 2 to 3 days, 8 to 10 days post-fertilization at 12 °C (Griffin and others 1998; Figure 2). Newly hatched, nearly transparent larvae retain a yolk-sac, are unable to feed for several days, and are approximately 6 to 9 mm in length (Alderdice and Velsen 1971; Barnhart 1988; Henri and others 1985). Larvae continue to develop for about 6 to 8 weeks. They slowly acquire the ability to feed and swim against currents. As juvenile fish, they migrate out of San Francisco Bay 6 to 7 months after fertilization.

Studies on herring from different regions suggests Pacific herring are extremely tolerant of a wide range of salinity at all life stages. The most recent research, however, raises questions about this conclusion, suggesting populations in different regions may possess different salinity tolerances.

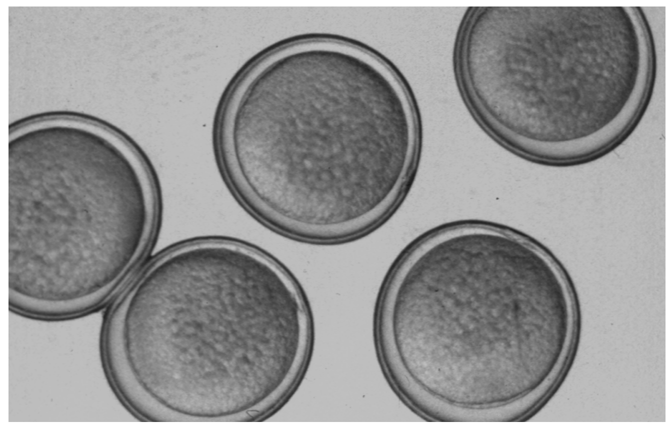

Figure 1 Pacific herring embryos depicting the elevation of the chorion from the egg surface, indicating that fertilization, but not first cleavage, has occurred

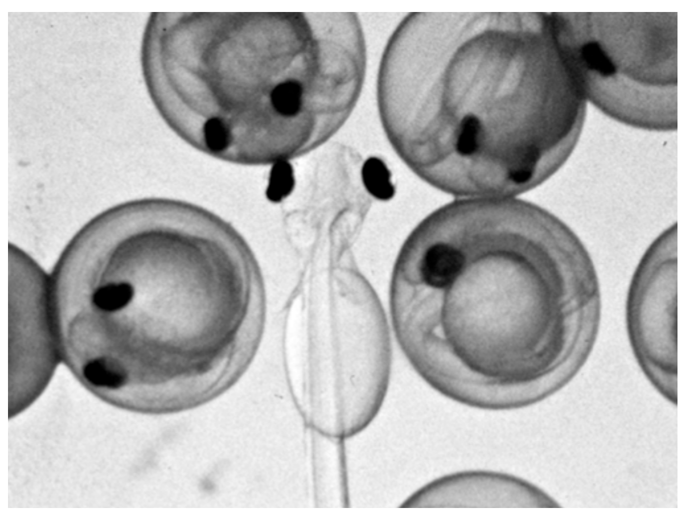

Figure 2 Pacific herring embryos and a larva (center) 8 days after fertilization. Development of eyes and a larval tail are evident in un-hatched embryos and the persisting yolk-sac is evident behind the head of the hatched larva.

Our laboratory reported that fertilization and embryonic development of San Francisco Bay herring occurred within a range of 8 to 28 ppt, with an optimal range of 12 to 24 ppt (Griffin and others 1998). Our optimal range was similar to another reported for herring from British Columbia (Alderdice and Hourston 1985). However, a third study found the optimal range to be higher, above a midpoint of 16 ppt (Dushkina 1973). Fertilization and embryonic development were much reduced outside of the optimal range and approached zero below 8 ppt and above 28 ppt.

As Yanagimachi first suggested, both low and high salinity affect fertilization by perturbing sperm motility (Griffin and others 1998). The negative effects of low and high salinity on larval production, in addition to cessation of embryonic development, include incidences of partial hatching at low salinity, and delayed hatching at high salinity (Dushkina 1973; Griffin and others 1998). The ability of larvae to tolerate a particular salinity may be associated with water temperature and with the salinity regime during embryonic development. Dueñas (1981) reported that British Columbia Pacific herring embryos survived at higher salinity levels when raised at low temperatures—those that survived elevated salinity and low temperature during embryonic development were the most tolerant of high post-hatch salinity.

Larval behavior also is affected by salinity. Dushkina (1973) reported that larvae from embryos that developed in <16 ppt water did not survive transition to the feeding stage, while those from embryos that developed in 16 to 34 ppt lived through the transition to feeding competency. In preliminary studies with San Francisco Bay herring larvae we have found that larvae survive better at 16 ppt than at either low (4 ppt) or high (32 ppt) salinity. Further, exposure to a salinity lower than at embryonic development is tolerated, while transfer to a higher salinity is often fatal (unpublished).

Hokkaido Herring Studies

Estuaries on the eastern shores of Hokkaido, Japan, have historically supported Pacific herring spawns that occur under different water temperature regimes, but what appear to be similar salinity regimes in similar environments as those determined to be optimal for San Francisco Bay herring. Akkeshi-ko, located at 43°2'N 144°52'E, is a shallow subarctic estuary that covers 32 km^2 and averages less than 2 m deep (Figure 3). The predominant freshwater input is from the Bekanbeusi River, which drains a watershed of 680 km^2, while the output is a deep water, marine embayment, Akkeshi Bay that joins the Pacific Ocean. The natural substrate under Akkeshi-ko, fine silt, is covered with Zostera (eelgrass) beds, on which herring are believed to spawn. The herring spawning season in Akkeshi-ko lasts only two to four weeks, beginning in early to mid-April (T. Matsubara, personal communication.). This period is much shorter than in San Francisco Bay where the reproductive season extends from November–December through March–April, depending on the year. The timing of the spawning season in Hokkaido appears to be driven by the release of the estuary from subzero winter temperatures that result in frequent ice cover of the estuary and high winter salinity conditions due to a lack of freshwater input. The spring thaw in both the estuary and watershed bring about increased temperatures and reduced salinity. Measurements taken during April by one group of researchers demonstrated that spring to early summer (April-June) were the times of lowest salinity in Akkeshi-ko and were times when salinity was within the optimal range that has been determined for herring in other regions and cited earlier. Salinity varied depending on location within the estuary from 1 ppt at the mouth of the Bekanbeusi River to 27.1 ppt at the entrance to Akkeshi Bay, with an overall average of 20.1 ppt in April 1994 and salinity remained in the low 20 ppt range through June of the same year (Iizumi and others 1995). Temperatures begin low (0 to 4 °C) at the time of spawning and increase to 12 °C or above during the larval period.

Spawning and embryonic development have not been followed in Akkeshi-ko. Interestingly, the actual spawning sites within the estuary have not been documented although it is known that herring enter Akkeshi-ko to spawn since a commercial herring trap net fishery is centered in the estuary (T. Matsubara, personal communication). Information on fertilization, embryonic development, and larval stages of Akkeshi-ko herring comes from hatchery-raised herring at the JSFA Station. This facility, initiated by the JSFA and the Japan Fisheries Agency, restores and supplements marine organisms of commercial importance through hatchery rearing and stocking of the marine environment. Reproductive herring caught in Akkeshi-ko are brought to the facility and young are reared from fertilization to the juvenile stage before being released. Production of Pacific herring larvae began in 1982 with the release of 25,000 juveniles and has continued to expand. In 1995 over 900,000 juveniles were released; the number surpassed 1,000,000 in 1999 (Y. Yamamoto, personal communication). Until the recent season, information about early life stages of Akkeshi-ko herring came primarily from this facility.

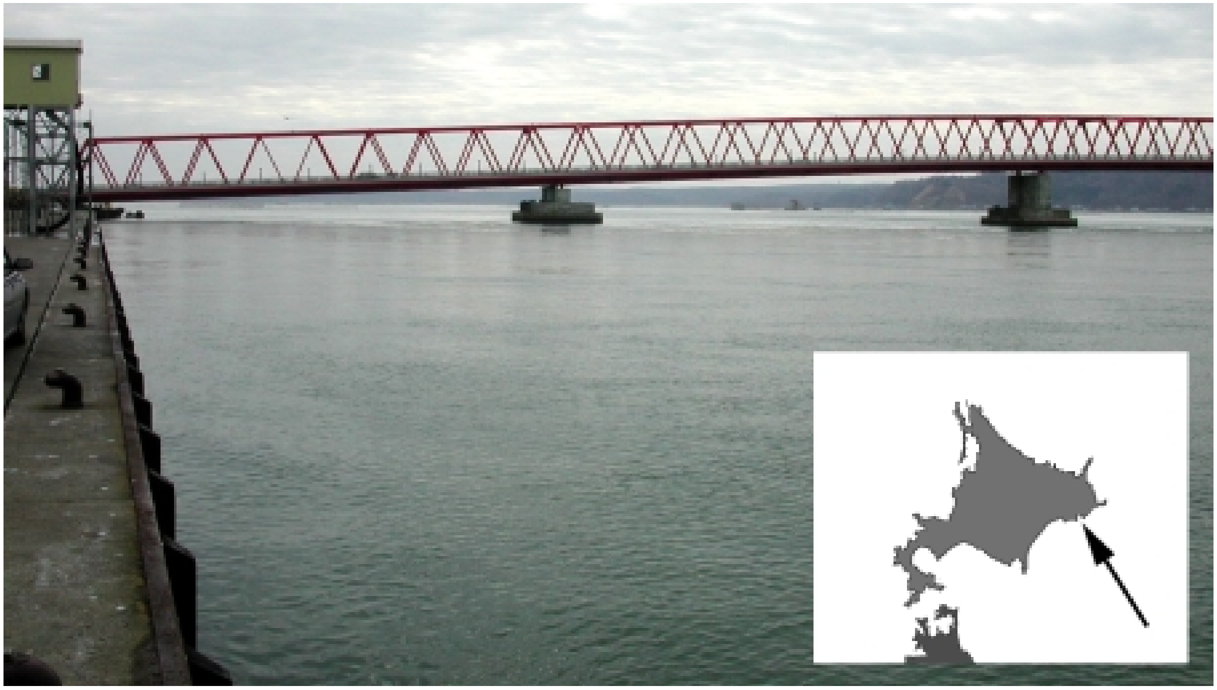

Figure 3 A view eastward toward Akkeshi-ko from the town of Kushiro which is situated on Akkeshi Bay. Inset shows location of Akkeshi Bay and Akkeshi-ko on Hokkaido.

At the facility eggs and sperm are stripped from gravid adults, mixed, and incubated through embryonic and larval development. Two different incubation temperatures have been used. Originally, ambient water temperature, 3 to 5 °C, was used along with an ambient salinity of 31 ppt. The facility draws water from the open coast, not the bay or estuary. Incubation temperatures for embryonic development were increased by heating water to 10 °C at a salinity of 31 ppt. Hatching occurs 14 days after fertilization at 10 °C and 40 days after fertilization at 3 to 5 °C. Both development times are within ranges published for herring from San Francisco and British Columbia. Interestingly, larval hatching rates 30% to 40% at 3 to 5 °C increased to 50% at 10 °C. These percentages are above those described for San Francisco Bay and suggest there is either a positive low temperature effect on hatching rate or that the Akkeshi-ko population is better adapted to high salinity than is the San Francisco Bay population. Preliminary results point to a low temperature effect. During the 2001 season we fertilized eggs from Akkeshi-ko fish and investigated the salinity tolerance for embryonic development at a higher temperature. At 12 °C, the incubation temperature used in experiments with San Francisco Bay herring embryos, Akkeshi-ko herring display the same salinity tolerance range, with an optimal range between 12 and 24 ppt.

After embryos hatch at the Akkeshi Station the temperature of the water is increased during larval rearing period to 14 to 15 °C, temperatures comparable with those in Akkeshi-ko for that time of year. The total length of time for rearing at the Akkeshi Station is 70 days post-hatching during which time larvae become juveniles about 45 to 50 mm in length. At this size the juvenile herring are transferred to fine mesh holding cages, located in Akkeshi-ko, for a two week intermediate rearing period to be weaned from the artificial hatchery diet to natural zooplankton that are present in Akkeshi-ko. Typically fish reach 60 to 70 mm in length during the intermediate rearing period, after which they are released into Akkeshi-ko. Prior to transfer to intermediate rearing sites in Akkeshi-ko, juvenile herring are marked so that hatchery reared fish can be distinguished from wild spawned fish. Alizarin, a red fluorescent dye that binds to calcified structures, is used to label the otoliths of juvenile fish. Thus, in Akkeshi we have the opportunity of comparing progeny of wild spawned fish with those of fish that have been hatchery reared.

We suppose there is a physiological cost to embryonic development of herring at non-optimal salinity. We expect that within a population adapted to reproduce in estuarine conditions individual embryos and larvae will display a range of tolerance for salinity. We see that within the tolerable salinity range for herring development, the numbers that survive increases as the optimum salinity is approached. Two possible mechanisms can explain survival in low or high salinity. First, salinity tolerance has a genetic basis and populations display diversity with respect to this tolerance. Second, the salinity history and/or condition of reproductive fish prior to spawning could affect the condition and stress tolerance ability of embryos and larvae. Distinguishing between these two explanations has importance for the understanding and management of herring populations in both San Francisco Bay and Akkeshi-ko.

In Akkeshi-ko, the herring population is being supplemented with animals raised at elevated salinity levels. The possibility exists that hatchery conditions are producing embryos and larvae that are adapted only to high salinity during early life stages. This may, in the long run, result in a reduction of genetic diversity with respect to salinity tolerance. Conversely, if differential salinity tolerance does not have a genetic basis, the techniques used in Akkeshi would not produce fish that can tolerate high salinity at early life stages. Determination of the causes of salinity tolerance in herring embryos and larvae has special significance for understanding reproductive success in San Francisco Bay herring. Local populations must be able to tolerate conditions more variable and extreme than Akkeshi-ko fish since San Francisco Bay temperatures can approach the upper limits for early life stages of Pacific herring and salinity is variable both between seasons and within a single reproductive season. If differences in individual salinity tolerance do in fact have a genetic basis, diversity in an estuary like San Francisco Bay may be critical to long-term survival of the population.

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Notes

Dr. Takahiro Matsubara. Hokkaido National Fisheries Research Institute; Kushiro, Hokkaido, Japan. Personal conversation with Fred Griffin in April of 200 and 2001.

Mr. Yoshihisa Yamamoto. Japan Sea Farming Association, Akkeshi Station; Akkeshi, Hokkaido, Japan. Personal conversation with Fred Griffin and written translation of JSFA brochure dated 1996.

Growth of Larval Striped Bass in the San Francisco Estuary

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Introduction

Abundance of juvenile striped bass has decreased in the San Francisco Estuary (Stevens and others 1985; Kohlhorst 1999) and before 1994, adult abundance had decreased. Juvenile striped bass have declined steadily, although irregularly, since the mid-1960s because of entrainment losses of eggs and young fish at water diversions, reduced freshwater flows due to water diversions and an extended drought, and the cumulative effects these factors have had on the number of adults and their egg production (Stevens and others 1985). After declining by about 40% after 1976, the adult population remained relatively stable at a lower level until a further decline in 1990, then fell to its lowest level in 1993, about one-third the average in the early 1970s (Kohlhorst 1999). Since 1993, adult abundance has rebounded, although juvenile abundance remains low.

Studies of San Francisco Estuary larval striped bass indicate that larval survival is critical in determining year class strength of early juvenile stages, but factors affecting growth and survival of larvae need to be explored to better understand striped bass population dynamics. Recently, Kimmerer and others (2000) have reported that early survival is moderated by density-dependent mortality during autumn of the first year of life and that increased mortality of adults, as well as reduced recruitment, has contributed to decreased egg production. Low and Miller (1986) found high positive correlations between the 38-mm abundance index, a measure of juvenile stage recruitment, and abundance indices of larvae 9 to 11 mm and 12 to 14 mm.

Growth of striped bass larvae is strongly influenced by temperature (Rogers and Westin 1981; Dey 1981; Uphoff 1989) and zooplankton prey density (Eldridge and others 1982; Chesney 1989; Tsai 1991), which vary annually in response to weather and freshwater outflow during spawning (late April through June). Field studies in Chesapeake Bay compared seasonal and annual otolith-estimated growth rates for larval striped bass and related these growth rates to environmental variables, especially water temperature and zooplankton density (Martin and

Setzler-Hamilton 1983, as cited in Rutherford and others 1997; Rutherford and Houde 1995; Secor and Houde 1995). Larval striped bass in the Potomac River grew fastest when zooplankton densities and temperatures were highest (Martin and Setzler-Hamilton 1983, as cited in Rutherford and others 1997). Growth rates of striped bass cohorts in Chesapeake Bay tributaries were positively related to water temperature, but were negatively related to copepod nauplii densities (Rutherford and Houde 1995). However, growth rates of cohorts were unrelated to water temperature and zooplankton densities in the Patuxent River (Secor and Houde 1995). In the Hudson River, larval striped bass growth rates have been linked to temperature and blooms of cladocerans (Limburg and others 1999).

Daily deposition of otolith increments must be validated before growth rates of larvae caught in the field can be estimated. Otolith increments are deposited daily for San Francisco Estuary striped bass and first increments formed at an average fish length of 4.0 mm (Foss and Miller 1996), the approximate size of striped bass at hatching (Eldridge and others 1982).

We had four objectives for this investigation: (1) to estimate growth rates of field-caught larvae by the otolith increment method; (2) to compare interannual variation in larval growth rates; (3) to compare larval growth rates from different salinity ranges; and (4) to examine possible relationships between growth rates and variation in temperature, food availability, and mortality and density of striped bass larvae.

Materials and Methods

Field Collections

We collected striped bass larvae from 1984 to 1993 by 10-minute oblique bottom to surface tows with a 505-µm mesh net. Before 1989, fish were sampled every 10 days at locations where striped bass were abundant. From 1989 to 1993, fish were collected as part of the egg and larva survey (IEP 1997). Water temperature, specific conductance, and water transparency (Secchi disc depth) were measured at each site. In 1989, fish were initially preserved in formalin and then transferred to 95% ethanol within 24 hours. After 1989, net-captured larvae were preserved in 95% ethanol in the field. Larvae were later rehydrated and measured to the nearest 0.1-mm standard length (SL).

The number of sample collection sites varied and their distribution within the study area was limited during 1984 to 1988. Fish were collected at only 5 sites in 1986, and more than 80% of the fish were collected from only 1 site (#15), just downstream of the junction of the Sacramento and San Joaquin rivers (Figure 1). Fish were collected at only 3 sites in 1988 and 63% of those came from 1 site (#47) on the San Joaquin River. Otolith samples were more evenly distributed during 1989 to 1993; no more than 30% of the fish were collected at any 1 site in any year and fish came from no fewer than 12 sites in any year. Sample sites were in 3 main areas: Suisun Bay, the Sacramento River and the San Joaquin River, but otoliths were not collected in all areas in some years before 1989.

Laboratory Methods

Sagittal otoliths, the largest and most easily readable of the 3 otolith pairs, were removed and cleaned. Otoliths from fish >10.5 mm were mounted, embedded in epoxide resin, ground with 400 and 600-grit sandpaper, and polished with alumina powder. We examined otoliths using a light microscope at 400x or 1000x magnification, fitted with a video camera, monitor, and Macintosh computer with “Bony Parts” image analysis system (Cailliet and others 1996) to aid increment counting through image enhancement.

Statistical Methods

We estimated mean annual growth rates of 6- to 14-mm striped bass by year from 1984 to 1993, except 1987, by regressing length on estimated age. Growth was estimated from the entire sample of age estimates; no estimates were deleted. Annual differences in growth rates were tested by analysis of covariance, with age as the covariate. We used Student’s *t*-test to make 36 pairwise comparisons ($k = n\ (n - 1)/2$) between annual growth coefficients; for an experiment-wise error rate of 0.05. The Bonferonni correction yielded an α of 0.0014 for each comparison (SAS 1989).

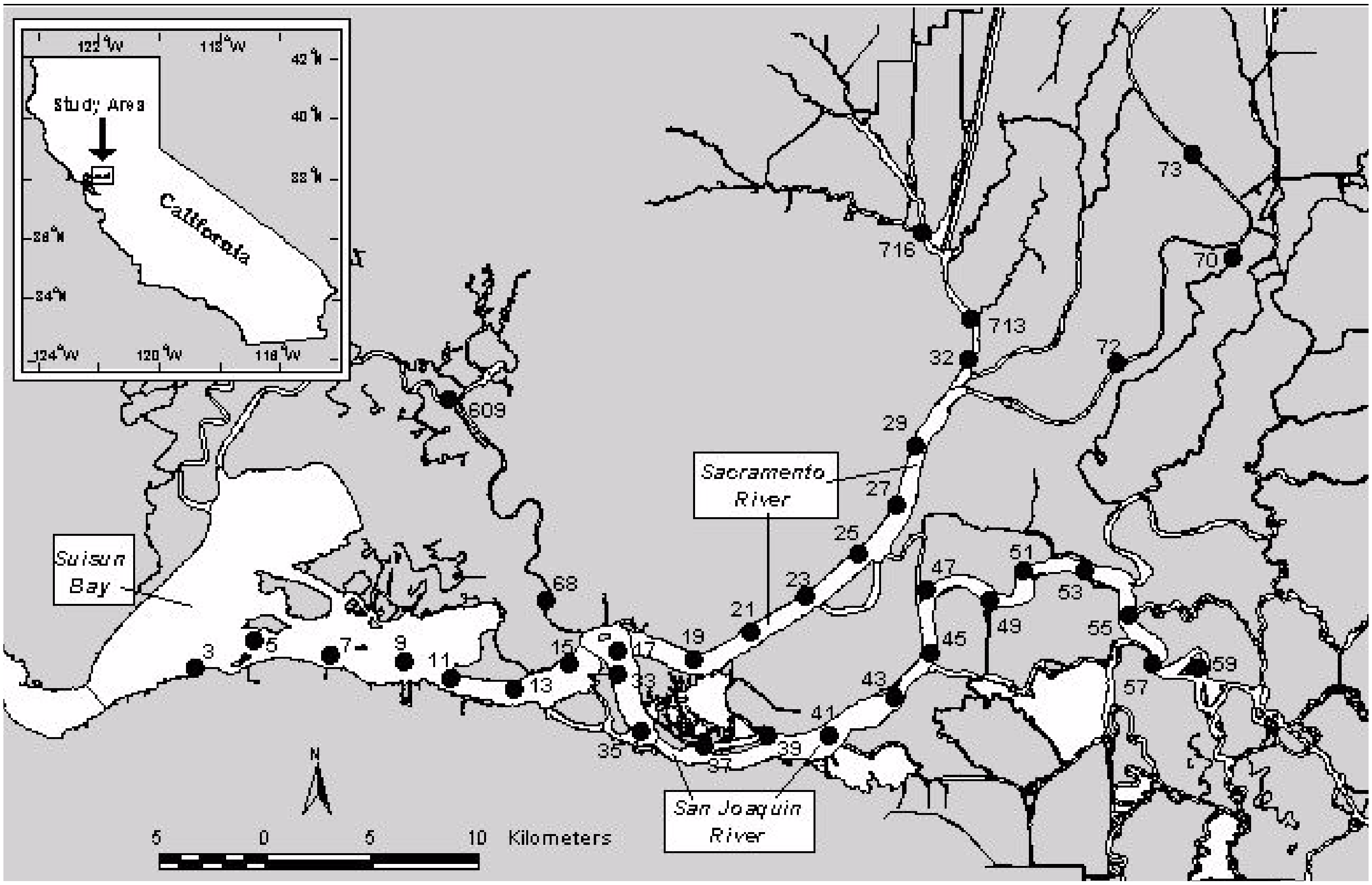

Figure 1 Larval striped bass sampling sites in the San Francisco Estuary

We compared growth rates to mean annual zooplankton densities. We collected zooplankton coincident with striped bass eggs and larvae using a Clarke-Bumpus No. 10 net (154 µm mesh). We determined important prey items by stomach analysis of larvae (DFG, unpublished data) and we obtained estimates of the relative contribution of food organisms in the diet by weighting the numbers per stomach by estimates of the average dry weight for each taxon. We calculated mean weighted zooplankton densities for April through July for sites where the density of 6- to 8-mm striped bass was >0. We used 6- to 8-mm fish because fish <6 mm were not efficiently sampled.

Larval growth rates were compared between fresh and brackish water by 2 approaches based on the number of otoliths sampled at higher salinities. In the first approach, we divided 6 years of data (1988–1993) into 2 groups based on surface conductance (<1 mS/cm and >1 mS/cm) because in some of these years too few fish were caught at higher conductances to use more than 2 groupings. We tested mean differences using Student's *t*-test ($P = 0.05$). However, for 1989–1992, catches were sufficient to divide conductances into 7 groups from <0.5 mS/cm to >3 mS/cm by 0.5-mS/cm increments. We regressed mean growth rates for each of these conductance groups on their discrete group number (1 to 7). Conductance was measured from bottom samples 1.5 to 12.2 m deep.

We examined the relationship between growth rates and zooplankton biomass from freshwater and brackish habitats by regressing mean annual 6- to 14-mm growth rates on mean annual prey densities (µg/m^3 dry weight) in each habitat (> or <1 mS/cm) from 1988 to 1993. Differences between regression slopes and elevations were tested using ANCOVA.

We analyzed mean annual larval growth rates for association with mean annual April–July water temperatures using simple linear correlation. Water temperature measurements were from a continuous monitoring site in the San Joaquin River near Antioch.

To examine whether growth rate variation was density dependent, we correlated mean annual densities for each 1-mm length group, from 6 to 14 mm, with mean annual 6- to14-mm growth rates.

We compared growth rates of 6- to 14-mm striped bass to mean instantaneous daily mortality rates using simple linear correlation. We estimated mortality rates by regressing $\log_e$ (estimated abundance-at-length) on the mean estimated age of each 1-mm length class between 6 and 14 mm. Regression coefficients were estimates of instantaneous daily mortality rates (Z).

We did not attempt an analysis of cohort-specific growth rates because few cohorts were sampled sufficiently to estimate growth rates over the entire 6- to 14-mm size range. In general, 10- to 14-mm striped bass were under-represented.

Results

Growth Rate Estimation

Linear models provided good fits to annual age-length data for 6- to 14-mm fish (Figure 2). Estimated ages ranged from 1 to 64 days and estimated annual growth rates of 6- to 14-mm striped bass varied from 0.13 to 0.27 mm/day (Table 1). Larvae grew slowest in 1989 and fastest in 1992 and estimated growth rates increased each year between 1989 and 1992. Analysis of covariance showed a significant difference between annual slopes ($F = 145.96$; df = 8, 2725; $P = 0.0001$). Growth rates for 1992 and 1993 were not significantly different from each other, but were significantly higher than all other years and the growth rate for 1989 was significantly lower than growth rates for all other years (Table 2).

Table 1 Otolith-based growth rates (G), instantaneous daily mortality rates (Z), age ranges, sample sizes, and environmental data for 6- to 14-mm striped bass. G/Z is the ratio of daily growth to daily mortality rates. Outflow is April–June mean total delta outflow.

Year	*G*	*Z*	*G/Z*	*Age range (days)*	*N*	*Outflow (m^3/s)*	*Prey density (mg/m^3)*	*Mean water temp (°C)*
1984	0.158	0.092	1.72	1 – 56	177	321	3,881	19.9
1985	0.187	0.153	1.22	5 – 44	33	184	3,790	19.7
1986	0.212	0.122	1.74	3 – 40	194	675	6,271	19.4
1988	0.157	0.111	1.41	3 – 43	260	183	1,682	19.8
1989	0.129	0.123	1.05	2 – 64	629	241	6,077	19.0
1990	0.156	0.128	1.22	4 – 60	404	177	17,392	19.7
1991	0.213	0.161	1.32	3 – 44	439	111	9,464	18.4
1992	0.270	0.097	2.78	2 – 35	371	125	39,095	19.8
1993	0.263	0.148	1.78	1 – 31	236	911	20,715	19.4

Table 2 Significant differences between 6- to 14-mm striped bass annual growth rates using a *t*-test with Bonferonni correction. X = nonsignificant at $P > 0.0014$. SH = significantly higher at $P \leq 0.0014$, SL = significantly lower at $P \leq 0.0014$. Cells designated SH indicate that the column year is significantly higher than the row year. Cells designated SL indicate that the column year is significantly lower than the row year.

Year	*1984*	*1985*	*1986*	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*
1984	---	X	SH	X	SL	X	SH	SH	SH
1985		----	X	X	SL	X	X	SH	SH
1986			----	SL	SL	SL	X	SH	SH
1988				----	SL	X	SH	SH	SH
1989					----	SH	SH	SH	SH
1990						----	SH	SH	SH
1991							----	SH	SH
1992								----	X
1993									----

Effects of Environmental Variables on Growth

Mean annual growth rate and prey density were positively related ($r = 0.72$; $P = 0.003$) (Figure 3). Prey densities in 1992, the year of greatest growth, were more than ten times greater than prey densities in some other years (Table 1).

Growth rates were not significantly correlated with densities of 6-, 7-, and 8-mm striped bass, but were significantly and positively correlated with densities of each length group from 9 to 14 mm (Table 3).

Mean annual growth rates (9 years) were not significantly related to mean conductivity at the time and place where the fish were collected ($r = -0.07$; $P = 0.85$). However, for the 4-year sample split into 7 conductivity ranges, growth rates significantly increased with conductance in 2 of the 4 years (1990 and 1992) (Figure 4).

For the 6-year sample split into 2 conductivity ranges, growth rates were significantly greater for fish collected at higher salinities in 1990, 1991, and 1992 (Table 4); however, in 1988, 1989, and 1993 growth rates were not significantly different between habitats. Contrary to expectations, prey densities were greater in fresh water than in brackish water in 1990 and 1991, 2 of the 3 years when growth was significantly faster in brackish water (Table 5). Growth rate-zooplankton density regression slopes ($P = 0.80$) and elevations ($P = 0.71$) for fresh water and brackish water were not significantly different and neither slope differed significantly from 0 ($P = 0.09$; $P = 0.06$).

Mean annual water temperatures during the growth period did not explain any of the variation in growth rates ($r = -0.05$; $P = 0.91$). Mean annual temperatures varied by <1.5 °C (Table 1).

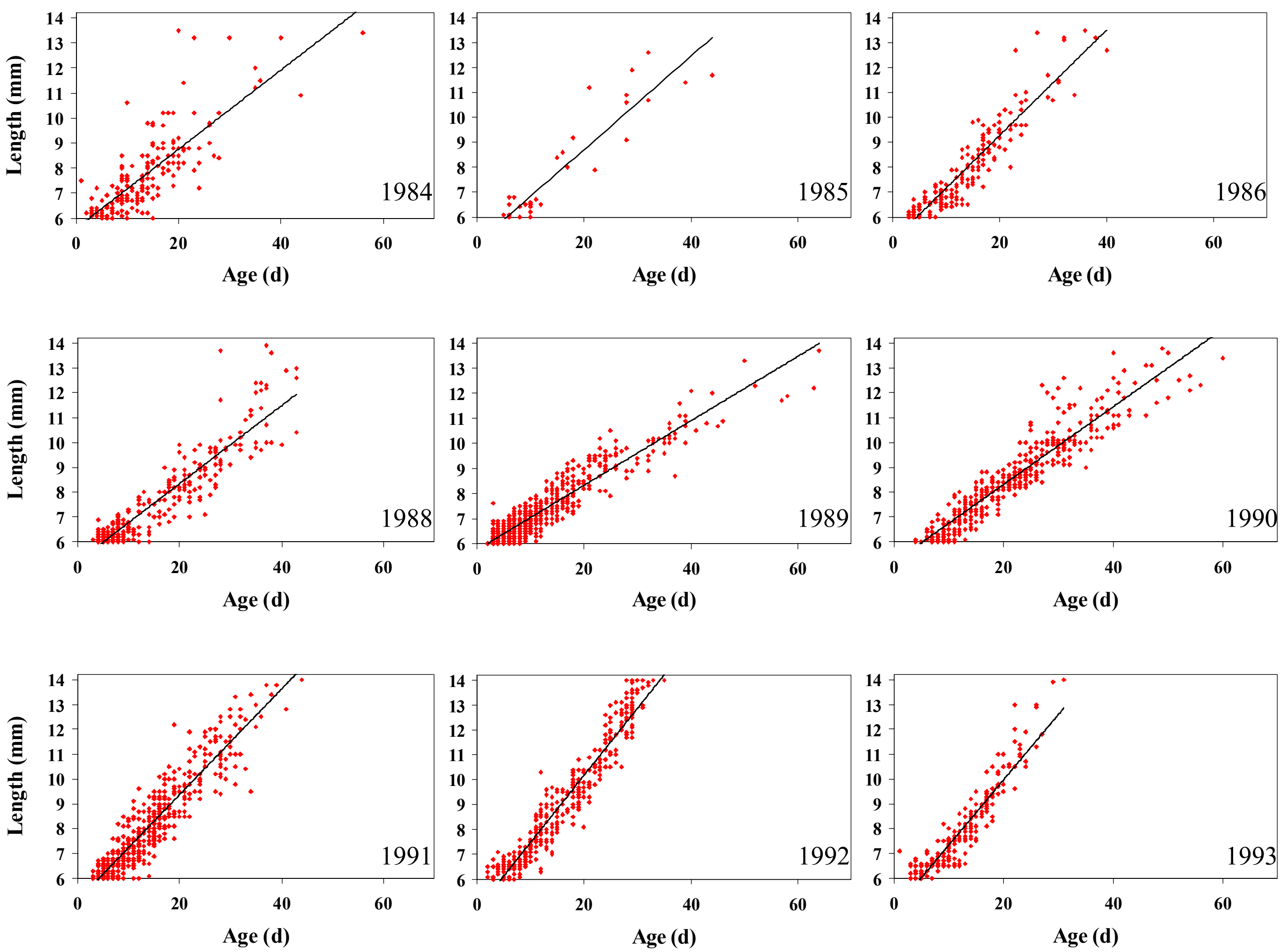

Figure 2 Age-length relationships for otolith-aged larval striped bass from the San Francisco Estuary, 1984–1993

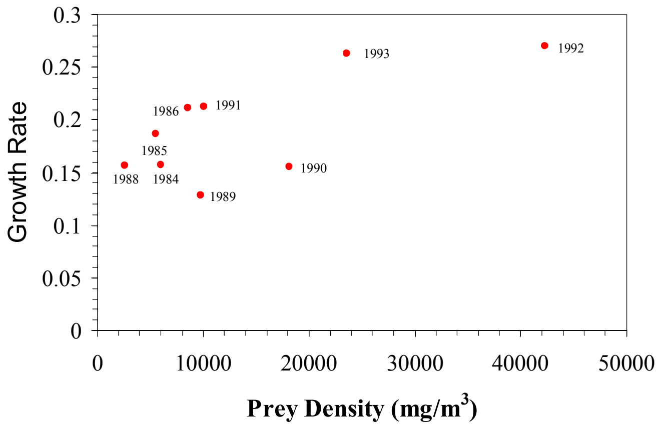

Figure 3 Mean annual April–July, 6- to 14-mm striped bass growth rates, and mean annual zooplankton density, where 6- to 8-mm striped bass were sampled in the San Francisco Estuary

Table 3 Comparison of mean annual densities for 1-mm length groups to mean annual 6- to 14-mm growth rates. *r* = Pearson correlation coefficient, *P* = probability > *r* under H_o: *r* = 0.

	Length group (mm)								
Statistic	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*
r	–0.33	0.05	0.52	0.86	0.84	0.88	0.89	0.76	0.80
P	0.39	0.90	0.15	0.003	0.005	0.002	0.001	0.02	0.009

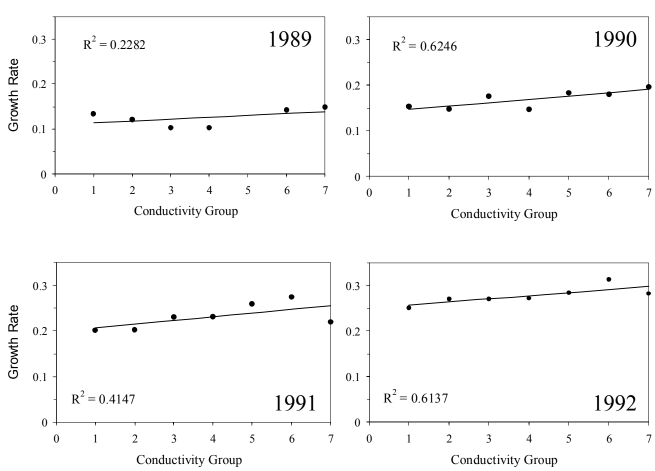

Figure 4 Mean annual 6- to 14-mm striped bass growth rates for 7 conductance groups (1989–1992). Group 1: <500 µS/cm; group 2: 500–999 µS/cm; group 3: 1,000–1,499 µS/cm; group 4: 1,500–1,999 µS/cm; group 5: 2,000–2,499 µS/cm; group 6: 2,500–2,999 µS/cm; group 7: ≥3,000 µS/cm.

Table 4 Growth rates for 6- to 14-mm striped bass for 2 habitats characterized as low conductance (<1 mS/cm) and higher conductance (≥1 mS/cm). *P* for *t*-test (α = 0.05).

Year	*Growth rate (sample size)*		
Specific conductance (mS/cm)	*<1*	*≥1*	*P*
1988	0.159 (214)	0.128 (46)	0.20
1989	0.131 (548)	0.122 (81)	0.08
1990	0.150 (233)	0.169 (171)	0.004
1991	0.203 (247)	0.233 (192)	0.0005
1992	0.262 (224)	0.279 (147)	0.04
1993	0.264 (191)	0.247 (45)	0.40

Table 5 Prey density (mg/m^3), water temperature, and water transparency (Secchi disc) for 2 habitats in the San Francisco Estuary for years in which growth was significantly greater in more saline water. Group 1 = bottom specific conductance <1 mS/cm, Group 2 = bottom specific conductance ≥1 mS/cm.

Year	*Prey density*		*Temp (°C)*		*Secchi (cm)*	
Specific conductance (mS/cm)	<1	1	<1	1	<1	1
1990	15,663	7,902	19.6	18.8	57	45
1991	8,855	3,335	17.9	17.1	50	31
1992	30,273	38,334	20.0	19.4	65	40

Growth vs. Mortality and Juvenile Abundance

Growth rates of larvae were not significantly correlated with either mortality rates (*r* = 0.16; *P* = 0.67) or the 38-mm abundance index (*r* = 0.26; *P* = 0.50). Mean daily instantaneous mortality rates for 6- to 14-mm striped bass ranged from 0.09 in 1984 to 0.16 in 1991. Although growth rates and mortality rates were not significantly correlated, mortality rates generally increased with growth rates, except in 1993 (Figure 5).

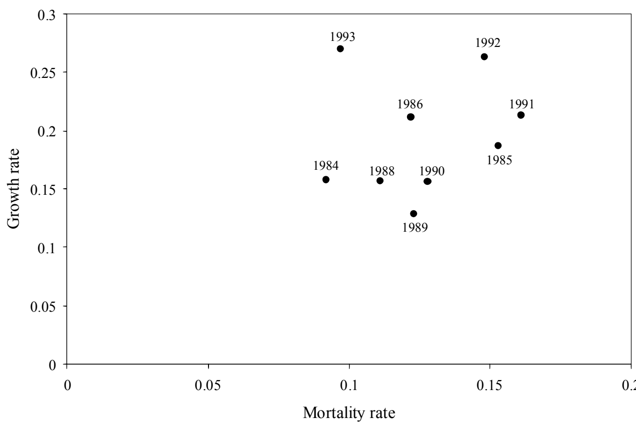

Figure 5 Mean annual 6- to 14-mm striped bass growth rates versus mean annual 6- to 14-mm striped bass instantaneous daily mortality rates from the San Francisco Estuary, 1989–1992

Discussion

Annually, growth of San Francisco Estuary striped bass larvae ranged from 0.13 to 0.27 mm/day, similar to otolith-derived rates for Atlantic Coast striped bass. Cohort-specific growth rates were 0.15 to 0.22 mm/day between ages 0 and 25 days for fish from the Patuxent River (Secor and Houde 1995) and annual means of cohort growth rates were between 0.18 and 0.26 mm/day for Potomac River fish (Rutherford and Houde 1995). Wild 25-day-old striped bass in the Patuxent River grew at a rate of 0.17 mm/day (Secor and others 1995). Our growth rates were slightly lower than the mean annual growth rate of 0.28 mm/day reported by Houde and others (1988), for 1987 Potomac River striped bass up to 42 days old, but similar to the 0.22 to 0.27 mm/day aggregate-sample rates found by Rutherford and others (1997), for 5- to 20-day-old fish from the Potomac River and Upper Chesapeake Bay.

A potential source of error in growth rate estimation may occur in years with slower growth. In these years, the sample tends to be composed of older fish. Otoliths of older fish are more difficult to read because complexity of otolith structure increases with otolith size (Campana and Neilson 1985; Jones and Brothers 1987; Foss and Miller 1996), and may result in overaging, which causes underestimation of growth rates. This may have occurred in 1989, when the standard length-age relationship was non-linear and indicates probable overaging.

Annual variation in growth rates was best explained by mean annual prey densities. Higher growth rates in 1992 and 1993 were associated with high prey densities, which were more than double those of most other years, but growth rates in 1989 and 1990 were low relative to prey densities.

Zooplankton densities from the San Francisco Estuary were ten times lower than those found in Chesapeake Bay tributaries (Rutherford and others 1997), but average growth rates were only 19% lower than average growth rates in the Chesapeake system. Although lower prey densities resulted in slower growth in the San Francisco system, the population effect is unclear because growth rates of larvae were not significantly correlated with the 38-mm abundance index. Since zooplankton densities appear to be limiting growth rates in some years, environmental conditions that increase productivity and standing crops of zooplankton in this estuary should benefit striped bass larvae.

Larval striped bass from brackish water grew significantly faster than those from fresh water in half the years analyzed, but mean annual growth between habitats did not differ significantly in the other 3 years. Growth rate differences between habitats in 3 years apparently were not due to prey density differences or temperature differences between habitats. Water transparency (Secchi depth) is lower in brackish habitats and may cause differences in prey capture rates, and thus growth rates, between habitats.

None of the correlation analyses provide support for density-dependent control of growth rates. The positive correlations between 9- to 14-mm length-group densities and growth rates and the lack of a significant relationship between 6- to 8-mm length-group densities and growth rates are contrary to a density-dependent effect on growth. Rutherford and others (1997) also concluded there was no support for density-dependent control of growth rates for Chesapeake Bay larval striped bass.

Faster growth did not result in higher survival of larvae or juveniles in the San Francisco Estuary as growth and mortality rates were not significantly correlated. A non-significant relationship also was reported for Potomac River striped bass (Rutherford and others 1997), although there was a similar positive trend of mortality rates increasing with growth rates. If such a relationship existed, it could operate through the following mechanism. Relatively large changes in survival and juvenile stage recruitment could result from small changes in larval striped bass growth rate by shortening larval stage duration in years when growth is fast, thereby decreasing the time larvae are vulnerable to predation (Houde 1987). But growth rates in the San Francisco Estuary were not significantly related to the striped bass 38-mm abundance index, a measure of juvenile recruitment.

We found that mean annual water temperatures during the larval growth period were not related to mean annual 6- to 14-mm growth rates, however, temperature effects may have been obscured by averages. Mean annual temperatures varied by <1.5 °C. Studies of Atlantic Coast larval striped bass cohorts found conflicting results when relating temperature to growth. Growth of 3-day Potomac River cohorts was correlated with temperature (Rutherford and Houde 1995), but Secor and Houde (1995) found 6-day cohort growth rates to be unrelated to temperature in the Patuxent River in 1991, though temperature was positively related to predicted mean lengths at 25 days. In the latter case, the authors suggested the effect of temperature may have been a result of increasing temperatures causing increased abundances of zooplankton. Pooled-sample growth rates of Potomac River larvae were positively correlated with mean temperatures from 1987 to 1989 (Rutherford and others 1997). Unfortunately, our data do not support a cohort analysis of larval striped bass which might better reveal relationships between growth and water temperature by focusing on short-term fluctuations in water temperature.

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Influence of Salinity, Bottom Topography, and Tides on Locations of Estuarine Turbidity Maxima in Northern San Francisco Bay

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Time series of salinity and suspended-solids concentration measured at four locations and vertical profiles of salinity and suspended-solids concentration measured during 48 water quality cruises from January 1993 to September 1997 are analyzed to describe the influence of salinity, bottom topography, and tides on locations of estuarine turbidity maxima in northern San Francisco Bay, California. Estuarine turbidity maxima form when salinity is present but they are not associated with a singular salinity. Bottom topography enhances salinity stratification, gravitational circulation and estuarine turbidity maxima formation seaward of sills. The spring–neap tidal cycle affects locations of estuarine turbidity maxima. Salinity stratification in Carquinez Strait, which is seaward of a sill, is greatest during neap tides, which is the only time when tidally averaged suspended-solids concentration in Carquinez Strait was less than that observed landward at Mallard Island. Spring tides cause the greatest vertical mixing and suspended-solids concentration in Carquinez Strait. Therefore, surface estuarine turbidity maxima always were located in or near the Strait (seaward of Middle Ground) during spring tide cruises, regardless of salinity. During neap tides, surface estuarine turbidity maxima always were observed in the landward half of the study area (landward of Middle Ground) and between 0 and 2 practical salinity units.

Introduction

A feature of many estuaries is a longitudinal maximum of suspended-solids concentration (SSC), called an estuarine turbidity maximum (ETM). Several processes can contribute to the formation of ETMs (Jay and Musiak 1994). Gravitational circulation or tidal asymmetry of velocity and SSC can cause convergent fluxes of suspended solids and form ETMs (Hamblin 1989; Jay and Musiak 1994; Wolanski and others 1995). Schubel and Carter (1984) state that the origin and maintenance of ETMs once was attributed to flocculation, but that nontidal (gravitational) circulation primarily is responsible. A cycle of local deposition, bed storage, and resuspension also can contribute to the formation of ETMs (Hamblin 1989; Uncles and others 1994; Wolanski and others 1995; Grabemann and others 1997). Suppression of turbulence by salinity stratification increases settling and trapping of fine sediment and may be a more effective trapping mechanism than gravitational circulation (Hamblin 1989; Geyer 1993).

Because gravitational circulation and stratification are dependent on the salinity field, ETMs often are located near a particular salinity. In the Tamar Estuary, an ETM is observed at the freshwater-saltwater interface or landward, and in the Weser Estuary an ETM is observed at 6 practical salinity units (psu) (Grabemann and others 1997). While ETMs typically are located at low salinities, they also can be located at much greater salinities. ETMs in Lorient and Vilaine bays are at salinities of about 18 psu and 25 to 30 psu, respectively (Le Bris and Glemarec 1996). Freshwater flow into an estuary affects the salinity field and, therefore, can affect the position of ETMs (Uncles and Stephens 1993; Grabemann and others 1997).

ETMs also may be located at longitudinally fixed locations, independent of salinity. Nonlinear interactions of first-order tides in channels with constrictions or decreasing depth in the landward direction may induce landward residual currents and convergence in part of the water column (Ianniello 1979), which results in a fixed, topographically controlled ETM (Jay and Musiak 1994). Wind-wave resuspension in shallow water and ebbtide transport to deeper channels also can create fixed locations for ETMs, such as in the Tay Estuary (Weir and McManus 1987).

Data from synoptic field measurements confirm the existence of an ETM in Suisun Bay (Figure 1), the most landward subembayment of northern San Francisco Bay (Meade 1972; Conomos and Peterson 1977; Arthur and Ball 1978). Ten synoptic measurements collected at high slack tide during spring and summer from 1974 to 1977 indicate that an ETM typically exists in the surface salinity range of 1 to 6 psu (Arthur and Ball 1978). ETM formation was attributed to gravitational circulation and flocculation. The 2-psu bottom isohaline is used as a habitat indicator to regulate freshwater flow to the Bay because it is believed to be an easily measured indicator of the location of the ETM and a salinity preferred by many estuarine species (Jassby and others 1995).

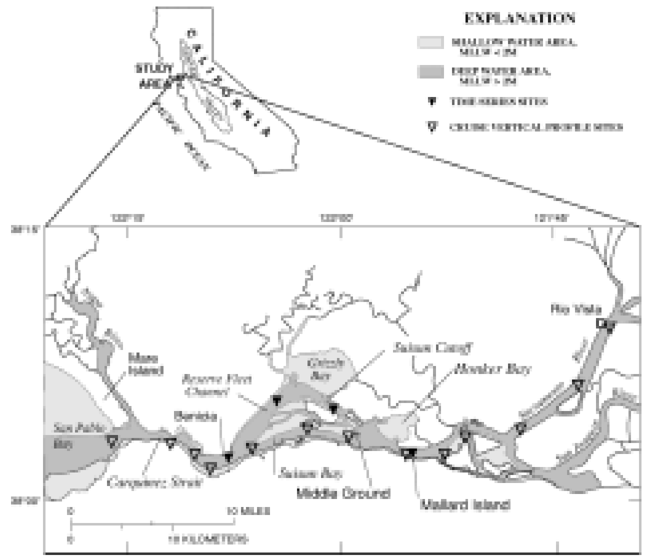

Figure 1 Northern San Francisco Bay, study area. MLLW = mean lower low water.

The purpose of this paper is to describe the influence of salinity, topography, and tides on the locations of ETMs in northern San Francisco Bay. The reasons for revisiting the issue of locations of ETMs in northern San Francisco Bay include availability of large data bases of vertical profiles and time series of salinity and SSC, evaluating the applicability of previously described ETM formation mechanisms, and improving the scientific basis for regulation of freshwater flow to the Bay.

Study Area

The region containing ETMs in northern San Francisco Bay is shown in Figure 1. Suisun Bay is the most landward subembayment of northern San Francisco Bay. The Sacramento and San Joaquin Rivers deliver freshwater to Suisun Bay, primarily during the winter rainy season and during the spring snowmelt and reservoir releases. The annual discharge of the Sacramento River is about six times greater than that of the San Joaquin River. Precipitation is negligible during late spring and summer. Suisun Bay is a partially mixed estuary that has extensive areas of shallow water that are less than 2 m deep at mean lower-low water (MLLW), including the subembayments of Grizzly and Honker Bays. Channels that are about 9 to 11 m deep are parallel to the southern and northwestern shores and are between Grizzly and Honker Bays. Carquinez Strait is a narrow channel about 18 m deep that connects Suisun Bay to San Pablo Bay, to the rest of San

Francisco Bay, and to the Pacific Ocean. Tides are mixed diurnal and semidiurnal and the tidal range varies from about 0.6 m during the weakest neap tides to 1.8 m during the strongest spring tides. Freshwater inflow typically first encounters saltwater in northern San Francisco Bay, defined here as the lower rivers, Suisun Bay, and Carquinez Strait. The salinity range in northern San Francisco Bay is about 0 to 25 psu and depends on the season and freshwater inflow. Suspended and bed sediment in Suisun Bay is predominately fine and cohesive, except for sandy bed sediment in some of the deeper channels (Conomos and Peterson 1977). The typical SSC range in northern San Francisco Bay is about 10 to 300 mg/L and sometimes up to about 1,000 mg/L at an ETM.

Vertical Profile and Time-Series Data

Vertical profile and time-series data are used to analyze the influence of salinity, bottom topography, tides, and water column position on observation of ETMs in northern San Francisco Bay. Vertical profiles of SSC and salinity are measured during approximately monthly water-quality surveys of San Francisco Bay (Edmunds and others 1997). Data are grouped into bins with a 1-m vertical resolution. Sampling sites in northern San Francisco Bay are shown in Figure 1. Cruises typically start near the time of slack before flood in Carquinez Strait and proceed land-ward (east), ending at Rio Vista a little more than 4 hours later, so the data are not truly synoptic. Data from 48 cruises from January 1993 to September 1997 for which the 2-psu surface isohaline was located in the study area are analyzed in this paper. Bottom salinity at Rio Vista, the most landward site, was less than or equal to 0.13 psu for all but two cruises. Thus, almost all cruises extend landward into virtu-ally freshwater.

In addition to the monthly vertical profile data, time series of SSC at fixed stations have been measured in Suisun Bay. SSC and salinity were measured at 10-minute intervals at a height of 0.6 m above the bed in the Reserve Fleet Channel and Suisun Cutoff in September and October 1995 (J. Cuetara U.S. Geological Survey, written communication 1998). SSC is measured at 15-minute intervals at the Benicia Bridge at 1 m and 16 m below MLLW and at Mallard Island 1 m below the water surface and 6 m below MLLW (Buchanan and Schoellhamer, 1998, Figure 1). Data collected at the surface from May to August 1996 are presented in this paper because a large range of salinities was measured as salt returned to Suisun Bay during the period.

Time series of salinity are measured by the National Oceanic and Atmospheric Administration (National Oceanic and Atmospheric Administration, 1998) at 6-minute intervals at the same elevations as SSC measurements at Benicia and by the California Department of Water Resources (DWR) (California Department of Water Resources, 1998) 1 m below the water surface at Mallard Island at 1-hour intervals. The salinity sensor at the bottom of the water column at Benicia failed in mid July 1996. NOAA also measures velocity profiles with an acoustic Doppler current pro-filer at 6-minute intervals at Benicia and DWR measures water surface elevation at hourly intervals at Mallard Island.

The time-series data were low-pass filtered to remove tidal frequencies and to provide a tidally averaged analysis of salinity and SSC. All low-pass filtering was performed with a Butterworth filter with a cutoff frequency of 0.0271 per hour. The strength of the spring/neap cycle at Benicia was quantified by calculating the low-pass root-mean-squared (RMS) water speed by squaring the measured water velocity 16 m below MLLW, low-pass filtering, and taking the square root. A RMS water-surface elevation at Mallard Island was calculated to quantify strength of the spring/neap cycle. For cruise data, NOAA tidal-current predictions for Carquinez Strait were used to delineate flood and ebb tides and to quantify the spring/neap cycle by taking the mean value of the four predicted maximum flood and ebb cur-rent speeds that were temporally centered on each cruise ($\overline{U}_{max}$).

Results: Cruise Data

Salinity and maximum cruise SSC are related near the water surface but not near the bed in northern San Francisco Bay. Maximum surface SSC, 1 m below the water surface, was located between 0-6 psu at the bottom for 67% of the cruises (Figure 2). Maximum SSC 1 m above the bed, however, was located over a wide range of bottom salinity. Only 23% of maximum bottom SSC was located between 0-6 psu at the bottom. Similar results were found at both elevations when surface salinity was considered. Seventy-one percent of the cruise data were collected during a predicted flood tide in Carquinez Strait. The effect of this flood tide sample bias is discussed later in this article.

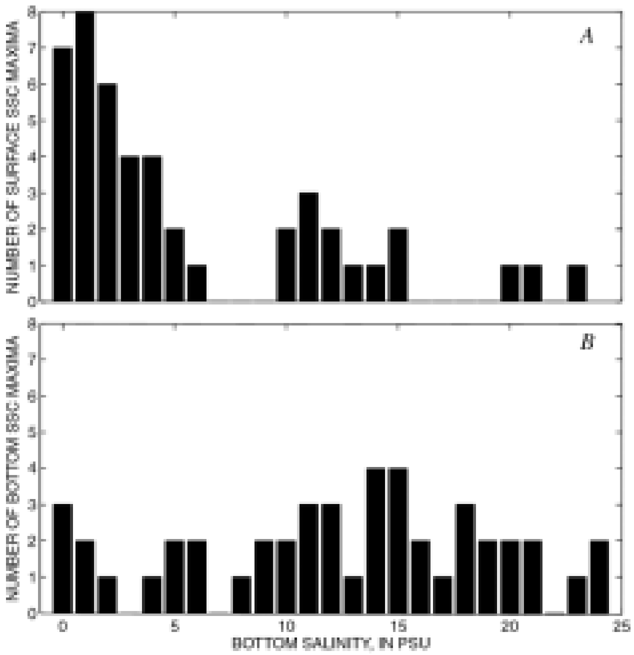

Figure 2 Positions of maximum cruise suspended-solids concentrations (SSC) at the surface (A) and bottom (B), relative to salinity, northern San Francisco Bay

Maximum SSC 1 m above the bed of northern San Francisco Bay, while not related to bottom salinity, is related to longitudinal position in the estuary. Maximum bottom SSC was located in Carquinez Strait during 67% of the cruises (Figure 3). Maximum surface SSC, however, was distributed throughout northern San Francisco Bay. Only 27% of maximum surface SSC were located in Carquinez Strait. Empirical-orthogonal-function analysis of the cruise data (not shown) produced similar results.

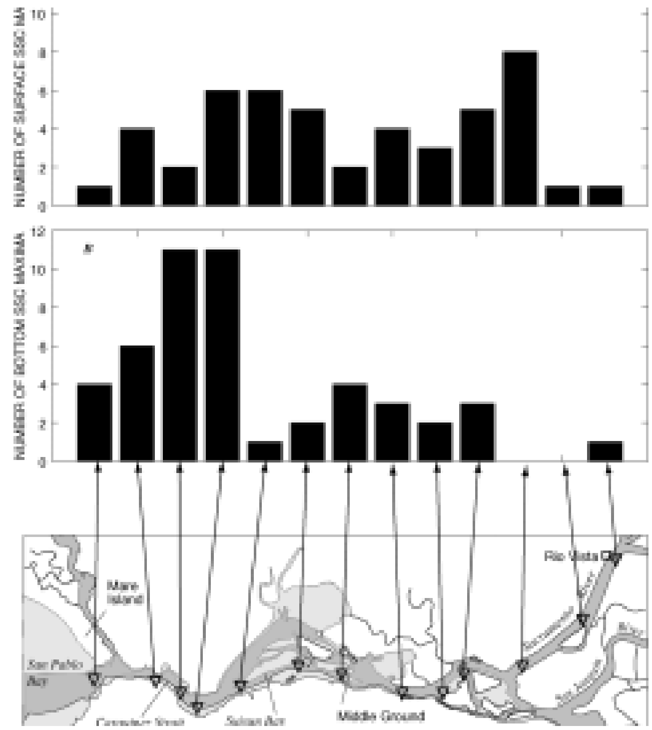

Figure 3 Position of maximum cruise suspended-solids concentration (SSC) at the surface (A) and bottom (B), relative to sampling site, northern San Francisco Bay

Results: Tidally Averaged Time-Series Data

During the dry season of spring and summer, when freshwater flows to the estuary decrease, salinity returns to northern San Francisco Bay. Tidally averaged surface salinity at Benicia, the seaward boundary of Suisun Bay, increased from 0 psu in late May to 10 psu in June 1996 (Figure 4). At Mallard Island, the landward boundary of Suisun Bay, tidally averaged surface salinity increased from 0-2 psu in late June 1996.

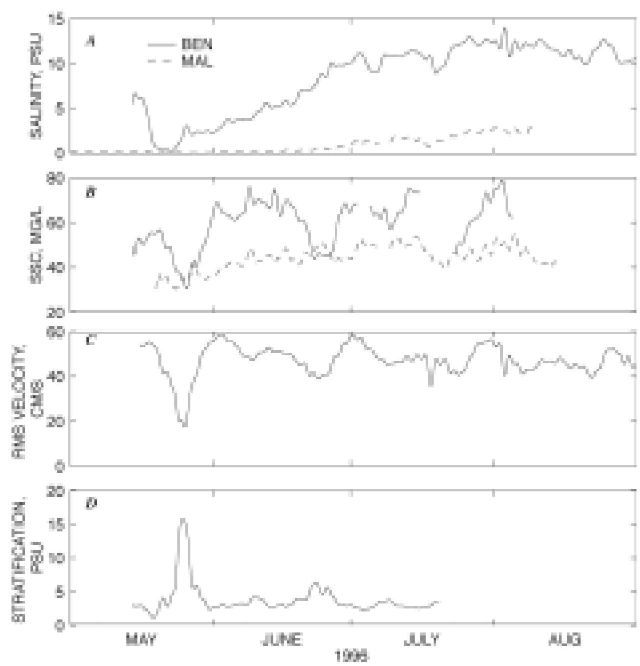

Figure 4 Tidally averaged surface salinity (A) and suspended-solids concentration (SSC) (B) at Benicia and Mallard Island; root-mean-squared (RMS) bottom velocity at Benicia (C); and tidally averaged salinity stratification at Benicia (D), northern San Francisco Bay

Tidally averaged surface SSC did not show any maxima associated with a particular tidally averaged salinity as salinity increased in Suisun Bay in 1996 (Figure 4). This result differs from the cruise data for which surface ETMs usually were observed between 0-6 psu bottom salinity. This discrepancy is discussed later in this article. Tidally averaged surface SSC almost always was greater at Benicia than at Mallard Island. SSC at Benicia varied with the spring/neap cycle, with minima during neap tides and maxima during spring tides. Tidally averaged SSC was slightly greater at Mallard Island only during weaker neap tides in late May and late June.

Similar results were found near the bed at two sites that are closer together as salinity returned to Suisun Bay after a wet rainy season in 1995. Tidally averaged salinity increased in the Reserve Fleet Channel (seaward site) and Suisun Cutoff (landward site) in October 1995, ranging from about 1-10 psu (Figure 5). Tidally aver-aged SSC always was greater in the Reserve Fleet Channel than in Suisun Cutoff, varied with the spring/neap cycle at both sites, and did not show any maxima associated with a particular salinity.

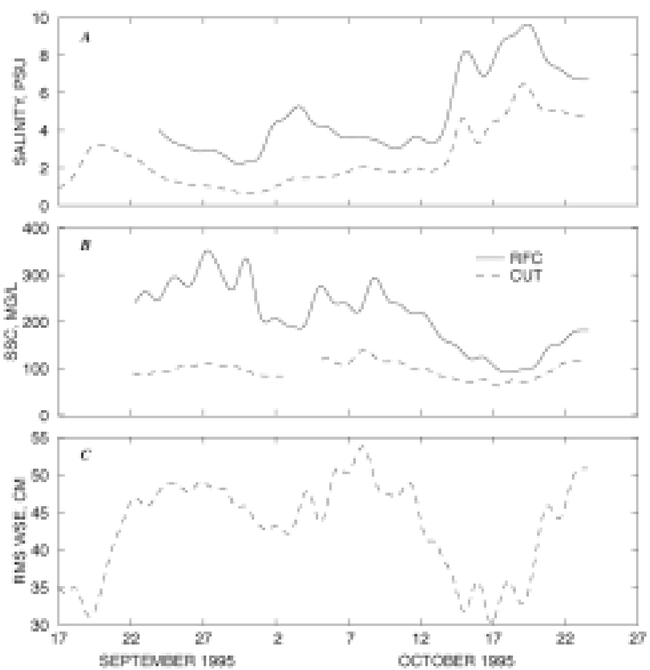

Figure 5 Tidally averaged bottom salinity (A) and suspended-solids concentration (SSC) (B) at the Reserve Fleet Channel and Suisun Cutoff; and root-mean-squared water-surface elevation (RMS WSE) at Suisun Cutoff (C), northern San Francisco Bay

Discussion

SSC maxima in northern San Francisco Bay are not associated with a singular salinity. Cruise data from northern San Francisco Bay indicate that there is an ETM at low salinity (0-6 psu) 1 m below the water surface. This is a larger salinity range for ETM location, however, than is observed in estuaries with a salinity-dependent ETM (Le Bris and Glemarec, 1996; Grabemann and others 1997). The processes that account for a salinity-dependent ETM, gravitational circulation, salinity stratification, and bed storage, occur in northern San Francisco Bay and are modified by bottom topography and tides.

Gravitational Circulation

A natural sill is located at the boundary of Carquinez Strait and Suisun Bay slightly landward (east) of the Benicia sampling site. There is a decrease in MLLW depth from 18-11 m in the landward direction at the sill. This topographic control places an upstream limit on gravitational circulation (Jay and Musiak, 1994; Burau and others 1998) that traps particles and creates an ETM in eastern Carquinez Strait. At the sill, the channel also bifurcates and the width of the southern channel is constricted, which also may limit gravitational circulation (Armi and Farmer 1986). Sites in Carquinez Strait had the greatest occurrence of SSC maxima at the bottom of the water column for the cruise data (Figure 3). Tidally averaged SSC almost always was greater at Benicia than at Mallard Island as salinity increased in Suisun Bay (Figure 4).

Another sill that supports the formation of an ETM in Suisun Bay is between the Reserve Fleet Channel and Suisun Cutoff sites. Two topographic features that place an upstream limit on gravitational circulation at the sill are a decrease in MLLW depth from 9-5 m in the landward direction at the sill and constriction of the channel in Suisun Cutoff (Burau and others 1998). This topographic control traps particles in the Reserve Fleet Channel. Tidally averaged SSC always was greater in the Reserve Fleet Channel than in Suisun Cutoff as salinity returned to Suisun Bay in 1995 (Figure 5). Gravitational circulation is driven by the longitudinal salinity gradient (Hansen and Rattray 1965), so these ETMs are dependent on the presence of a nonzero salinity gradient, not a particular salinity.

Salinity Stratification

Turbulence suppression by salinity stratification is most likely to occur in Carquinez Strait, where water depths in the study area are greatest (Burau and others 1998). Stratification is greatest during neap tides, which reduces vertical mixing, increases deposition, and decreases SSC (Figure 4). Neap tides are the only times when tidally averaged surface SSC is less at Benicia than at Mallard Island. For example, during a neap tide in late May 1996, tidally averaged stratification of almost 16 psu between surface and bottom measurements (15 m apart) account for the smallest tidally averaged SSC measured at Benicia during the study period. In addition, bottom velocities were negligible during ebb tides during this period (not shown), increasing the duration of slack tide to hours and enhancing deposition. Deposition during neap tides creates a supply of easily erodible sediment on the bed in Carquinez Strait. When tidal energy increases as the subsequent spring tide is approached, this sediment is resuspended and gravitational circulation keeps a portion of the sediment in Carquinez Strait, creating an ETM. Thus, deposition associated with salinity stratification and subsequent resuspension is a contributor to the ETM observed in Carquinez Strait.

Bed Storage

Increased sediment deposition associated with stratification is a source of suspended solids for bed storage in Carquinez Strait, especially at the subtidal time scale during neap tides. On the tidal time scale, slack tide in northern San Francisco Bay typically is only a few minutes in duration, which permits few of the suspended solids to deposit during a slack tide. In addition, the duration of high and low water slack tides in northern San Francisco Bay is symmetric. In contrast, high water slack in the Tamar Estuary lasts 2-3 hours, during which time suspended solids deposit on the bed (Uncles and Stephens, 1993). Asymmetry of slack tide duration in the Tamar Estuary also helps create an ETM at or landward of the freshwater/saltwater interface, which is not observed in northern San Francisco Bay.

Deposition and erosion cycles are more aligned with the spring-neap cycle than the tidal cycle. About one-half of the variance of SSC is caused by the spring- neap cycle, and SSC lags the spring-neap cycle by about 2 days (Schoellhamer, 1996). The relatively short duration of slack water limits the duration of deposition of suspended solids and consolidation of newly deposited bed sediment during the tidal cycle, so suspended solids accumulate in the water column as a spring tide is approached and slowly deposit as a neap tide is approached. Tidally averaged SSC in northern San Francisco Bay is similar to the spring/neap cycle (Figures 4 and 5). This observation is especially true at Benicia and the Reserve Fleet Channel where stratification and deposition are greatest at neap tide.

Wind-wave resuspension of bed sediment in shallow water subembayments is another topographically controlled source of suspended solids in northern San Francisco Bay. Major subembayments that are less than 2-m deep at MLLW are Grizzly and Honker Bays within Suisun Bay and San Pablo Bay, to the west of Carquinez Strait (Figure 1). An annual cycle of deposition and resuspension begins with a large influx of sediment during winter, primarily from the Central Valley, and much of this material deposits in San Pablo and Suisun Bays (Krone, 1979). Stronger winds during spring and summer cause wind-wave resuspension of bed sediment in these shallow waters and increase SSC (Krone, 1979; Schoellhamer, 1996, 1997). Gravitational circulation in Carquinez Strait transports suspended solids from San Pablo Bay to Suisun Bay (Conomos and Peterson, 1977).

Tides and Surface ETM Observation

There commonly is an ETM at low salinities (0-6 psu) near the surface, according to the cruise data (Figure 2), but not according to the tidally averaged data (Figures 4 and 5). Cruise data can be described as the sum of a tidally averaged component and a component representing the instantaneous deviation from the tidally averaged value. Thus, the instantaneous deviation component represents a tidal time-scale process that accounts for this discrepancy.

The cruise data are susceptible to biasing by tidal time-scale processes because 71% of the measurements during the cruises were made during a predicted flood tide in Carquinez Strait. Because of this sampling bias, the difference between the tidally averaged and cruise observations of the surface ETM location could be caused by a slack tide process that reduces SSC in Carquinez Strait or a flood tide process that increases SSC at low salinities.

Salinity-dependence and longitudinal position of the surface ETM observed during cruises is modulated by the spring/neap cycle. During neap tides ($\overline{U}_{max}$ <0.98 m/s), the surface ETM was located at salinities from 0 to 2 psu landward of Middle Ground in Suisun Bay (Figure 6). During spring tides ($\overline{U}_{max}$ >1.15 m/s), the surface ETM was seaward of Middle Ground (toward Mare Island) at salinities from 0.3 to 20.4 psu. Thus, the process that accounts for the difference in the surface ETM observations between the tidally averaged and cruise data is more pronounced during neap tides than during spring tides. Whether or not the spring/neap modulation is present during ebb tides cannot be determined from Figure 6 because no cruises were conducted during neap ebb tides.

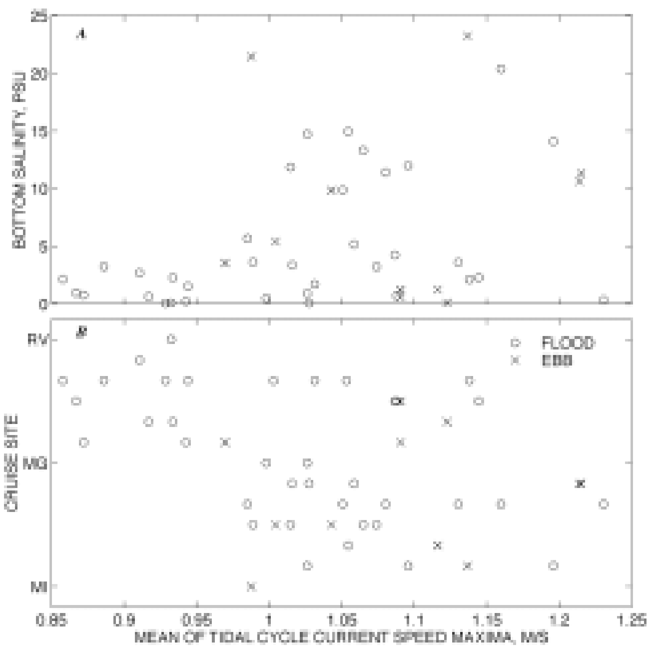

Figure 6 Bottom salinity (A) and sampling site (B) of the maximum cruise surface suspended-solids concentrations relative to the mean of the predicted tidal cycle current speed maxima ($\overline{U}_{max}$) in Carquinez Strait, northern San Francisco Bay. Predicted tidal currents in Carquinez Strait, at the time the maximum SSC for a cruise was sampled, were used to determine tidal phase. RV = Rio Vista; MG = Middle Ground; MI = Mare Island.

One process that could account for the difference between the tidally averaged and cruise observations of the surface ETM location is baroclinically driven pulses at the beginning of flood tide where the longitudinal baroclinic forcing is greatest (Burau and others 1998; Schoellhamer and Burau 1998). This location is where the longitudinal salinity gradient is greatest, which usually is where salinity is 0-2 psu. Pulses increase bed shear stress and vertical mixing and, thus, surface SSC. These pulses are strongest during neap tides and have been observed to cause tidally aver-aged landward transport of suspended solids, despite seaward water transport at mid-depth at Mallard Island during neap tides (Tobin and others 1995). The water-quality cruise data usually are collected during flood tide and, therefore, soon after a pulse.

Another process that could account for the difference between the tidally averaged and cruise observations of the surface ETM location is particle settling during slack tide in Carquinez Strait, which reduces surface SSC. Stratification in Carquinez Strait is greatest during neap tides, which reduces vertical mixing, enhances settling, and decreases tidally averaged surface SSC (Figure 4). During spring tides, stratification is reduced, so vertical mixing, bed-shear stress, and surface SSC are greater. During cruises, the surface ETM always was located in or near Carquinez Strait during spring tides, independent of the salinity (Figure 6).

Observed surface ETM location, relative to longitudinal position and salinity, is affected by semidiurnal and diurnal tides and the spring/neap tidal cycle. Flood- tide sampling bias during cruises, baroclinically driven pulses during flood tide, and spring/neap modulation of particle settling at slack tide in Carquinez Strait probably account for the discrepancy between the surface ETM location derived from tidally averaged data and cruise data.

Conclusions

Salinity, bottom topography, and tides affect the locations of estuarine turbidity maxima (ETM) in northern San Francisco Bay. ETMs are not associated with a singular salinity. Bottom suspended-solids concentration (SSC) during cruises and tidally averaged SSC did not show any maxima associated with a particular salinity. Observation of a surface ETM at 0-6 psu bottom salinity during 67% of the water-quality cruises probably is a result of (1) 71% of the cruise data being collected on flood tide, (2) baroclinically driven pulses during flood tide, and (3) spring/neap modulation of salinity stratification and particle settling at slack tide in Carquinez Strait. The longitudinal salinity gradient, not salinity, creates gravitational circulation and ETMs.

Bottom topography, especially sills in the channels, is another factor controlling the location of ETMs in northern San Francisco Bay. Locations of ETMs are related to bottom topography because salinity stratification and gravitational circulation are enhanced seaward of sills. Maximum bottom SSC was located in

Carquinez Strait during 67% of the cruises, and tidally averaged SSC was greater in Carquinez Strait and the Reserve Fleet Channel, which are both seaward of sills, compared with more landward sites. Vertical mixing and SSC are greatest in Carquinez Strait during spring tides. Therefore, surface ETMs were always located in or near the Strait (seaward of Middle Ground) during spring tide cruises, regardless of salinity. Wind-wave resuspension of bed sediment in shallow water subembayments is another topographically controlled source of suspended solids.

The spring/neap tidal cycle affects the locations of ETMs. Bottom shear stress and SSC are greatest during spring tides and smallest during neap tides. Salinity stratification in Carquinez Strait is greatest during neap tides, which is the only time when tidally averaged SSC in Carquinez Strait was less than at a landward site at Mallard Island. Baroclinically driven pulses also are strongest during neap tides, when a sur-face ETM always was observed in the eastern half of the study area (landward of Middle Ground) and between 0-2 psu during cruises.

Observations of an ETM can be affected by sample timing, relative to the tidal cycle. The design of estuarine water-quality sampling programs should consider variability caused by diurnal and semidiurnal tides and the spring/neap cycle, whenever practical.

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Announcements

IEP Sponsors Symposium and Proceedings: Early Life History of Fishes in the San Francisco Estuary and Watershed

Fred Feyrer (DWR), ffeyrer@water.ca.gov;
Larry Brown (USGS); Randy Brown (DWR, retired); Jim Orsi (DFG, retired); and Mike Chotkowski (USBR)

The IEP will sponsor a symposium titled "Early Life History of Fishes in the San Francisco Estuary and Watershed" to disseminate information about the ecology of larval and early juvenile fishes in the San Francisco Estuary and watershed.

The American Fisheries Society will publish the symposium proceedings and the authors of this announcement will serve as volume editors. To date, agency, academic, and consulting biologists have submitted 26 papers on a variety of topics.

Contact Fred Feyrer (ffeyrer@water.ca.gov) if you are interested in submitting a paper for publication in the volume.

Forming a California Affiliate of the Estuarine Research Federation: An Update

Randy Brown (DWR, retired), rl_brown@pacbell.net;
Wim Kimmerer (SFSU); and Fred Nichols (USGS, retired)

Over the past several months we have been working to form the California Estuarine Research Society (CAERS), a new addition to the five existing local ERF affiliates. We've made much progress since April 2001.

- Wim revised the proposed bylaws based on comments received.
- Randy filed articles of incorporation with the Secretary of State.
- At the recent State of the Estuary Conference we met with Joy Bartholomew, ERF Executive Director, to discuss the proposed society and how it can function within ERF.
- Fred compiled a list of the e-mail addresses of California ERF members.
- We developed a proposed slate of officers.
- We discussed options for frequency, format and location of CAERS meetings. We are thinking about annual meetings, using an informal format held in conjunction with other meetings, and possibly, separate meetings to address specific topics.
- We agreed that CAERS would be a California (and perhaps Mexico) affiliate, not just a resurrection of the old San Francisco Bay and Estuarine Association. We also agreed that CAERS would not be restricted solely to estuarine researchers. Many scientists working along the coast, and even in "blue water," can benefit from informal information exchange.
- Finally we agreed that for CAERS to succeed, we will have to form and maintain an organization that provides value added. We recognize that everyone is busy and has many options for conference and meeting attendance.

Our next steps are outlined below.

- File papers to obtain tax-exempt status.
- Contact as many prospective members as possible.
- Collect dues ($10/year) from interested individuals and elect officers.
- Establish a website. In the meantime, we will post information on the ERF website (http://erf.org)
- Plan the first meeting.

Anyone interested in more information or with ideas (especially for meeting topics with broad appeal) about how CAERS can benefit scientists, interested managers, and the public, please contact Wim, Fred or me. We also will be contacting scientists in Monterey Bay, southern California, Bodega Bay and Humboldt to solicit interest and participation in CAERS. When you receive the e-mail from us describing the proposed organization, pass it along to colleagues you believe might be interested in becoming a member of CAERS.

Annual Interagency Ecological Program Workshop

Zach Hymanson (DWR), zachary@water.ca.gov

The 2002 IEP Workshop will be February 27 through March 1, at the Asilomar Conference Center in Pacific Grove. The IEP workshop will provide information on a number of projects via talks, posters, and panel discussions. The IEP workshop will overlap with the Bay-Delta Modeling Forum workshop, held February 26 and 27, so you may attend all or part of both workshops.

The planning committee is now formulating an agenda for the IEP workshop, with the intent of having a final agenda in early December. The final agenda will be available at the IEP web page (www.iep.ca.gov). We are still working on registration details. Check the IEP web page in early November for registration information.

Poster presentations will again be an important part of the workshop. Titles for all poster presentations will be included in the 2002 workshop agenda. If you plan to present a poster at the workshop please contact Tanya Veldhuizen (tanyav@water.ca.gov) with the title of your poster. Please contact Zach Hymanson (zachary@water.ca.gov) for additional information about the IEP workshop. Please contact John Williams (jgwill@dcn.davis.ca.us) for additional information about the Bay-Delta Modeling Forum workshop.

Journal Publications by IEP Staff and Affiliates

Lauren Buffaloe (DWR), buffaloe@water.ca.gov

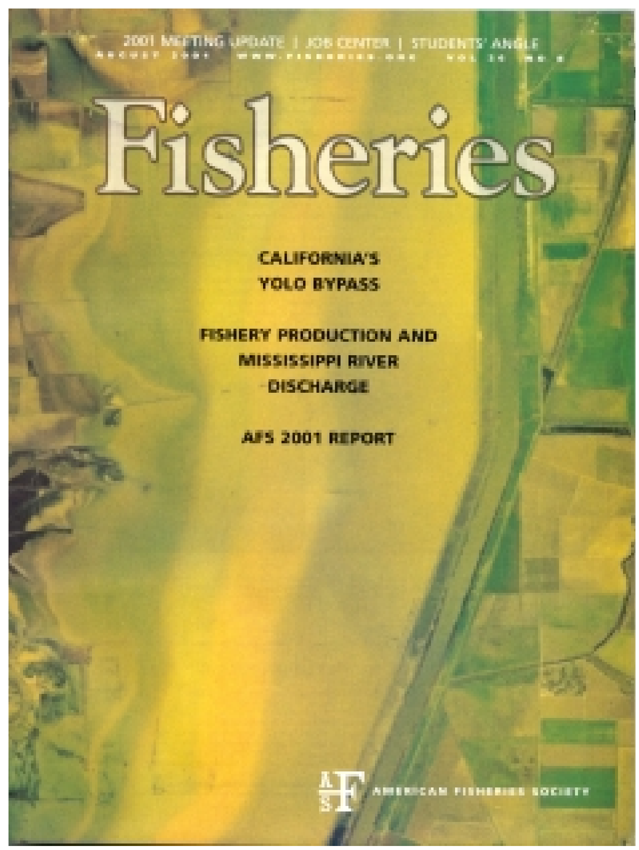
One of the unstated, yet important goals for publishing the *IEP Newsletter* is to encourage IEP and affiliated scientists to develop articles for publication in the open literature, especially for journal publication.

Recently, a few dedicated individuals have taken opportunity of this incentive. Wim Kimmerer and others published in *Estuaries* "Analysis of an Estuarine Striped Bass Population: Effects of Environmental Conditions During Early Life." Also, a paper by Ted Sommer and others "California's Yolo Bypass: Evidence that Flood Control Can Be Compatible with Fish, Wetlands, Wildlife and Agriculture," was published in *Fisheries*.

A complete reference listing of each paper follows, along with a color aerial photograph of a portion of the Yolo bypass, which incidentally, was selected as the cover photo for the *Fisheries* issue.

Kimmerer WJ, Cowan JH Jr, Miller LW, Rose KA. 2001. Analysis of an estuarine striped bass population: effects of environmental conditions during early life. Estuaries 24(4):557–75.

Sommer TR, Harrell WC, Nobriga M, Brown R, Moyle PB, Kimmerer WJ, Schemel L. 2001. California's Yolo Bypass: evidence that flood control can be compatible with fish, wetlands, wildlife and agriculture. Fisheries 26(8):6–16.



Here we have evidence that the motivation to publish , and the hard-won results, are working to achieve greater goals—to share and increase our knowledge of the complex ecosystem of the San Francisco Estuary and protect its natural resources.

Articles Published in Volume 14 of the *IEP Newsletter*

Number 1, Winter 2001

Simplified conversions between specific conductance and salinity units for use with data from monitoring stations
L. Schemel

Results of 2000 salt marsh harvest mouse surveys in Suisun Marsh
P. Finfrock

Suisun Marsh mappping
T. Keeler-Wolf, M. Vaghti, and A. Kilgore

Preliminary analysis of long-term benthic community change in Grizzly Bay
H. Peterson

Progress and development of delta smelt culture: year-end report 2000
B. Baskerville-Bridges, J. Lindberg, J. Van Eenennaam, and S. Doroshov

Synopsis of issues in developing the San Joaquin River Deep Water Ship Channel dissolved oxygen TMDL
G. F. Lee and A. Jones-Lee

Number 2, Spring 2001

Spring 2000 delta smelt salvage and delta hydrodynamics and an introduction to the delta smelt working group's decision tree
M. Nobriga, Z. Hymanson, K. Fleming, and C. Ruhl

Vernalis Adaptive Management Plan (VAMP) 2000 smolt survival investigations
P. Brandes

Number 3, Summer 2001

First observation of an exotic water flea in the Delta: *Daphnia lumholtzi*
A. Mueller-Solger

Preliminary validation of daily otolith ring deposition in juvenile splittail
F. Feyrer, G. O'Leary, T. Sommer, and B. Harrell

The Chinese mitten crab (*Eriocheir sinensis*) in Great Britain
Leif-Matthais Herborg

Tahoe and the Delta: some fundamental differences in conservation and restoration issues
A.D. Jassby, C.R. Goldman, and J.E. Reuter

Global climate change: potential effects on the Sacramento–San Joaquin Watershed and the San Francisco Estuary
N. Knowles and D. Cayan

Differences among hatchery and wild steelhead: evidence from Delta fish monitoring programs
M. Nobriga and P. Cadrett

Responses and recovery in delta smelt exposed to handling stress during fish treadmill experiments at winter temperature
P. Young, C. Swanson, S. Chun, T. Chen, T. MacColl, and J.J. Cech

Delta Water Project Operations

Kate Le (DWR), kle@water.ca.gov

Given the dry hydrologic conditions in water year 2001, flows on Sacramento and San Joaquin rivers and the Net Delta Outflow Index (NDOI) were quite low from July through September 2001 (Figure 1). San Joaquin River flow ranged between 33 and 45 cubic meters per second (1,170 cfs and 1,600 cfs), Sacramento flow ranged between 333 and 455 cubic meters per second (12,000 cfs to 16,000 cfs), and the NDOI ranged between 69 and 215 cubic meters per second (2,400 cfs and 7,600 cfs).

Exports at both Central Valley Project (CVP) and State Water Project (SWP) intakes were typical during this period. CVP pumping was more stable than SWP, except on July 22 and August 18, 2001. CVP pumping was reduced on these dates due to water level concerns in the south Delta. In late June, a leak on the SWP aqueduct was repaired. Soon after, SWP operators resumed pumping by increments during the first half of July 2001 (Figure 2). Significant increases and decreases in SWP pumping during July through September 2001 also are described below.

- July 16, 2001: pumping decreased due to maintenance.
- July 22 and August 18, 2001: SWP pumping increased to account for CVP reductions in pumping.
- August 10–12, August 28, and September 2, 2001: pumping decreased due to water quality concerns (Contra Costa 250 mg/L standard).

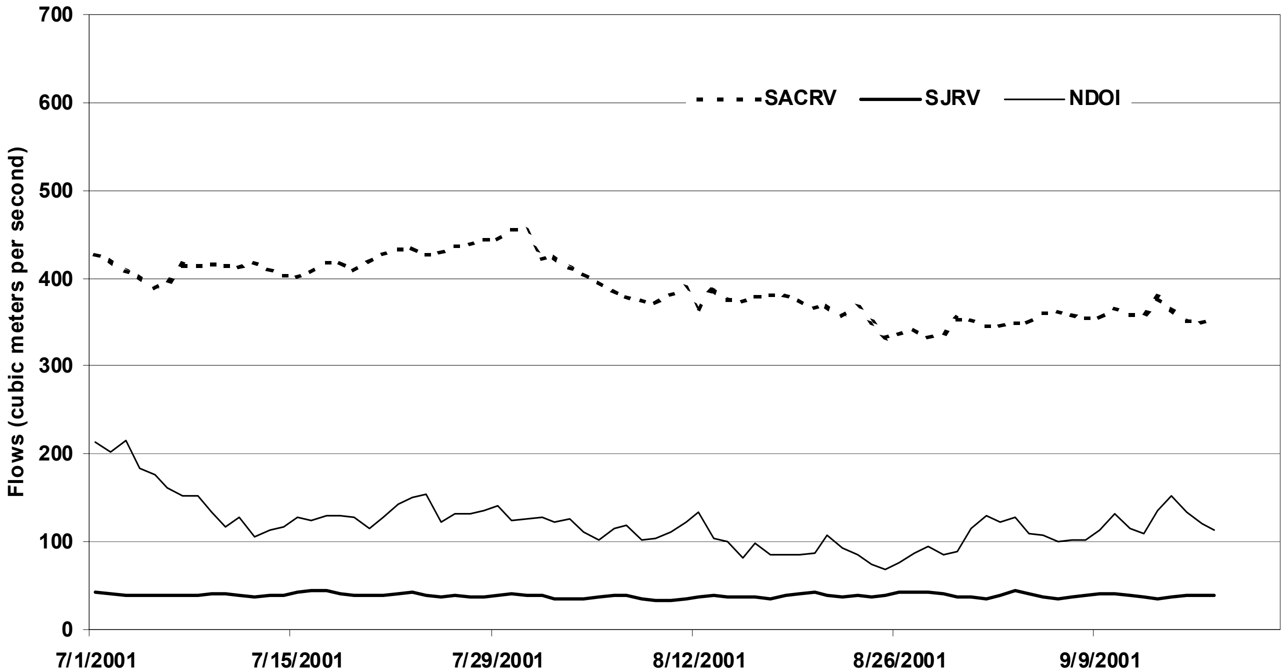


Figure 1 Sacramento and San Joaquin river flows and NDOI, July–September 2001

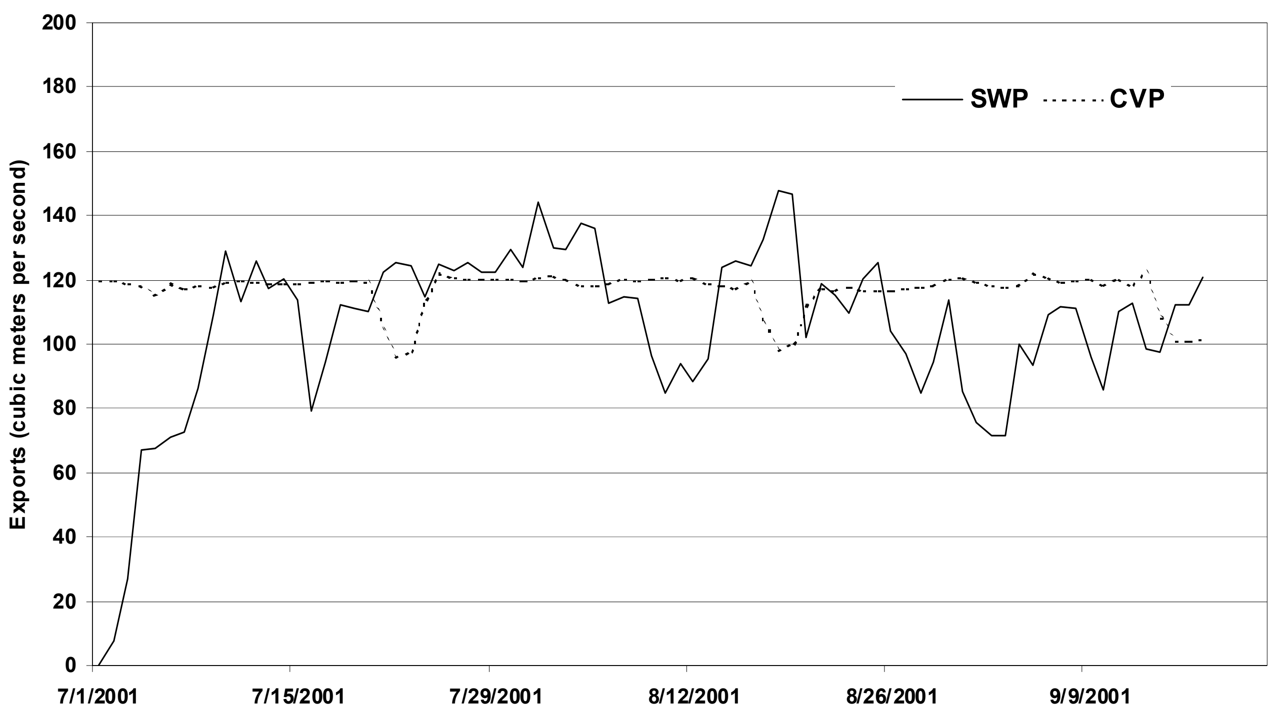


Figure 2 SWP and CVP pumping, July–September 2001

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For information about the Interagency Ecological Program, visit our website on-line at http://www.iep.water.ca.gov. Readers are encouraged to submit brief articles or ideas for articles. All correspondence, including submissions for publication, requests for copies, and mailing list changes should be addressed to Lauren Buffaloe, California Department of Water Resources, 3251 S Street, Sacramento, CA, 95816-7017.

IEP NEWSLETTER

Interagency Ecological Program for the San Francisco Estuary

The Interagency Ecological Program for the San Francisco Estuary
is a cooperative program of the

California Department of Water Resources
State Water Resources Control Board
US Bureau of Reclamation
US Army Corps of Engineers
California Department of Fish and Game
US Fish and Wildlife Service
US Geological Survey
US Environmental Protection Agency

National Marine Fisheries Service

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